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Ronald Hudson

HIGHWAY RESEARCH RECORD

Number 332

Highway Safety Improvements

5 Reports

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Subject Areas

22	Highway Design
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52	Road User Characteristics

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Foreword

Interest in traffic safety continues to command attention in many quarters. The 5 papers in this RECORD treat the subject from several different viewpoints and will be helpful to a broad range of engineers and safety specialists.

While others have studied the effect on accidents of the use of supplemental daytime running lights, Cantilli reports on the use of parking lights in lieu of added lights. A year's accident experience for some 200 vehicles with running lights was compared to that for some 400 vehicles without daytime lights. Those vehicles with lights had a better accident rate and a better severity rate than the unlighted vehicles. Variations by type of accident, type of vehicle, and color of vehicle are also discussed.

From a UCLA study of all aspects of highway collisions, VanWagoner concludes that a lack of communications exists between the highway designer and the safety researcher. He suggests that a structured group approach to highway design review from the safety point of view would help ensure that the intent of safety standards was fully considered.

Tamburri and Smith report the development of a safety index used by the California Division of Highways. It is defined as the percentage of the capital investment that will be returned to the motorist as savings in the cost of prevented accidents during the service life of an improvement project. Thought-provoking formal discussions by Mills and by Perini add to the usefulness of the report.

Concerned with the very severe, but relatively rare, cross-median crash, Wright, Hassell, and Arrillaga investigated it by using computer simulation. Six different variables were studied to determine their effects on probability of crash and on impact speed.

The final paper, by Baerwald, reports on the findings of a National Academy of Engineering interdisciplinary committee formed to study ambulance design criteria. Input from physicians, ambulance operators, automotive engineers, and other specialists in related fields resulted in specific ambulance design criteria recommendations, and these are summarized in the report. The report also contains information about the organization of the committee and concludes with information helpful in achieving success in interdisciplinary problem-solving.

Contents

Accident Experience With Parking Lights as Running Lights

EDMUND J. CANTILLI, Transportation Planning Division,
Polytechnic Institute of Brooklyn

This is a report on an attempt to test the need for better visual definition of the automotive vehicle through the use of running lights during daylight hours. In lieu of the addition of special lighting systems, the parking lights and taillights of some 200 motor vehicles were made to turn on automatically on ignition. After 1 year, observation of these vehicles, and of about 400 unmodified vehicles as a control group, gave results indicating that the modified vehicles as a group had a better accident rate (some 18 percent better overall) and a better severity rate (66 percent lower on a numerical scale) than the unlighted vehicles. Specifically, the rear-end accident rate was reduced by 45 percent, with significant reductions of other accident types. Variation by type of vehicle and color of vehicle are also discussed.

•AS A RESULT of a study by M. J. Allen and J. R. Clark (1) of Indiana University, the Port of New York Authority undertook in February 1965 a limited test of the concept of running lights for daylight operation of motor vehicles. Even though the Allen and Clark study recommended (and utilized) added light systems to test vehicles, the Port Authority (PA) experiment attempted to use the existing parking lights and taillights that are normally unused during daytime operation. In that experiment (2) 38 passenger cars from an automotive pool were modified so that parking lights and taillights turned on automatically on ignition. Results after 1 year showed that a statistically significant reduction in accident rate was experienced by the modified vehicles as against a control group of 200 unmodified cars (10.22 versus 19.20). In July 1967 approximately 200 vehicles, modified in the same manner, were studied in relation to about 400 unmodified vehicles for 1 year.

METHODOLOGY

Vehicles

From lists of the 1,367 PA vehicles of all kinds (listed by number), 600 vehicles in 3 categories (Table 1) were selected at random (excluding special types of vehicles and vehicles with other types of warning lights or flashing lights). Because of retirement and replacement of vehicles during the period of choice, and during the study period, the total number of vehicles involved was 578 at the beginning of the experiment year, and 557 at the end, for an average number of 567.5.

Accidents

Accidents included in the experiment were those that occurred during daylight, dawn, or dusk. The types considered are as follows:

1. Rear-end collision—when PA vehicle is struck in the rear by another vehicle;

Paper sponsored by Committee on Highway Safety and presented at the 49th Annual Meeting.

TABLE 1

VEHICLES USED IN THE EXPERIMENT

Vehicle	With Running Lights		Without Running Lights	
	Number	Percent	Number	Percent
Passenger	(115 + 126)/2 = 120.5	33.2	(244 + 241)/2 = 242.5	66.8
Black	(77 + 83)/2 = 80		(149 + 143)/2 = 146	
Yellow	(37 + 42/2 = 39.5		(89 + 92)/2 = 90.5	
Other (unmarked vehicle of PA police detective)	(1 + 1)/2 = 1		(6 + 6)/2 = 6	
Light trucks	(56 + 45)/2 = 50.5	32.8	(102 + 105)/2 = 103.5	67.2
Heavy trucks	(21 + 19)/2 = 20	39.6	(29 + 32)/2 = 30.5	60.4
All	(203 + 179)/2 = 191	33.66	(375 + 378)/2 = 376.5	66.34

Note: Police vehicles (yellow sedans and station wagons) with "lollipop" lights and rotating beacons were not used in this experiment.

2. Backing collision—when a vehicle backs into an occupied or moving PA vehicle (excluding a backing collision of a PA vehicle);
3. Right-angle collision—all types;
4. Sideswipe collision—when PA vehicle is sideswiped (excluding a PA vehicle sideswiping another vehicle);
5. Head-on collision—all except for the case when a vehicle is obviously out of control because of a vehicle defect or having struck a fixed object first or both; and
6. Sideswipe (opposite direction)—all except for the case when a vehicle is obviously out of control.

Accidents excluded are those that occur during hours of darkness and include the following:

1. Collision with fixed object;
2. Collision with object lying in the roadway;
3. Collision with falling or flying objects;
4. Vehicle damaged while parked;
5. Improper loading or load cover;
6. Vehicle turned over in the road;
7. Vehicle ran off the roadway; and
8. Rear-end collision—PA vehicle strikes another vehicle in the rear.

The accident rate used is accidents per million vehicle-miles. The severity rate is based on a system (3) developed for ascribing numerical values to classes of severity as follows:

Damage or Injury	Severity Factor
Property damage, under \$100	1
Property damage, \$100 to \$249	2
Property damage, \$250 and over	5
Negligible injury or injury claimed	5
Minor injury	15
Major injury	150
Fatality	350

The total severity is the sum of the severity factors of all accidents.

$$\text{Severity rate per 1,000,000 vehicle-miles} = \frac{\text{total severity} \times 1{,}000{,}000}{\text{actual vehicle-miles}}$$

For example, the severity rate for 2 accidents with property damage under \$100 (1), minor injury (15), and 120,000 vehicle-miles is as follows:

$$\text{Severity rate} = \frac{16 \times 1{,}000{,}000}{120{,}000} = 1.33$$

TABLE 2

TYPE OF ACCIDENTS AND MILEAGE BY MONTH
(All Vehicles and All Accidents)

Date	Vehicles With Running Lights								Vehicles Without Running Lights							
	Accident							Mileage	Accident							Mileage
	RE	A	SS	B	HO	PED	Total		RE	A	SS	B	HO	PED	Total	
July 1967		1					1	177,550	1			1			2	282,296
Aug. 1967								172,117								323,145
Sept. 1967								161,622	2	2		1			5	289,081
Oct. 1967			1				1	158,134				1			1	301,660
Nov. 1967			1	1			2	116,265	4	1	2	2			9	305,274
Dec. 1967		1	1				2	144,784	1	3					4	290,797
Jan. 1968	3			1			4	166,377	3	1	2	1	1		8	332,731
Feb. 1968	1		1				2	167,881			1			1	2	340,825
March 1968		1	2				3	163,556	1		1				2	351,241
April 1968	1						1	157,551	2	2					4	305,544
May 1968	1			1			2	182,648	3	3	2		1	1	10	387,850
June 1968	1	2					3	162,450	2		2				4	330,880
Total	7	5	6	3			21	1,930,835	19	12	10	6	2	2	51	3,841,324

Note: RE = rear end; A = angle; SS = sideswipe; B = backing; HO = head on; and PED = pedestrian.

RESULTS

A total of 72 accidents occurred to the study vehicles during the study year: 51 to those without running lights and 21 to those with running lights. A summary of the results by month is given in Table 2.

Figure 1 shows the distribution of accidents by month, day, and hour. The monthly fluctuations generally follow a seasonal pattern observed previously. The daily distribution shows a slight difference in pattern for the 2 groups, but the smaller numbers for accidents of vehicles with running lights may affect this. The distribution by hour shows general agreement in distribution.

Figure 2 shows the distribution of accidents by type. The effect of running lights on rear-end accidents especially is pronounced, even without adjustment on the basis of mileage covered. The distribution by severity classifications is shown in Figure 3. The dramatic reduction in severity is apparent, from 20 percent personal injury (and fatal) for vehicles without running lights.

Figure 4, distribution by light conditions, shows that a larger proportion of dawn or dusk accidents occurred to those vehicles with running lights. This may be indicative of the fact that many drivers turn on their parking lights or headlights during those periods. How many of the drivers of vehicles without running lights who might have

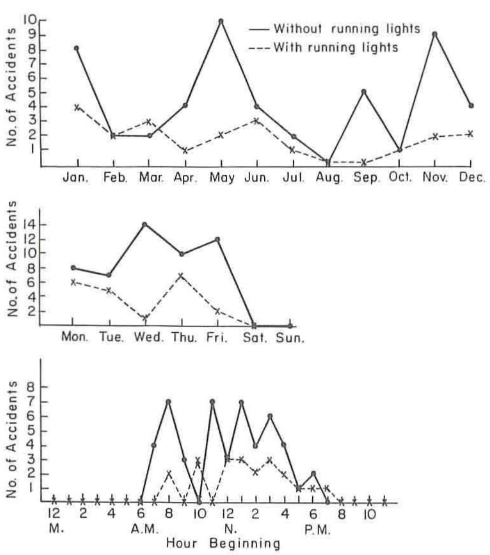

Figure 1. Accidents by month, day, and hour.

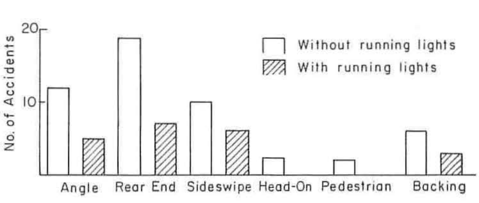

Figure 2. Accidents by type.

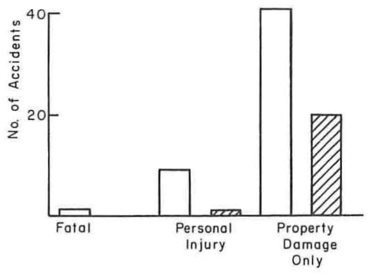

Figure 3. Accidents by severity.

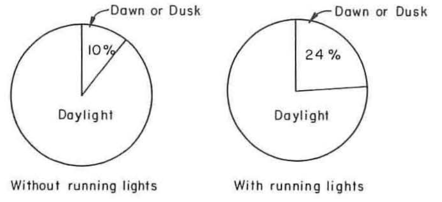

Figure 4. Accidents by light conditions.

done that is not known. It may also indicate the dissipation of the effectiveness of the concept during periods when all or most drivers are doing the same thing. The distribution by weather condition (Fig. 5) shows great improvement for daylight conditions, but not for those conditions during which lights might be turned on.

For the total period, all vehicles with running lights had 20 percent fewer accidents (Fig. 6) and about 66 percent fewer severe accidents. The greatest improvement by vehicle type was for passenger vehicles, which showed a 23 percent reduction in accident rate, and a 41 percent reduction in severity rate. Rear-end accidents showed a 45 percent improvement in accident rate and a 54 percent improvement in severity rate. In addition, there were improvements in the angle, backing, and head-on rates. However, there were more sideswipe accidents (per million vehicle-miles), and no improvement was shown for yellow vehicles or for trucks (which were mostly yellow).

Numbers of accidents, severity factors, and mileage were accumulated month by month, and a rate was calculated each month. The accident rate for all vehicles and all accident types (Fig. 7) for modified vehicles was considerably below the rate for the control group. The control group rate ranged from 10 to 34 percent greater than the modified group. At the end of the test period the control group was 22 percent more than the modified group. The severity rate was also consistently lower (Fig. 8). By t-test for statistical significance, these rates show a significant difference.

The rear-end accident rate for modified vehicles, which was perhaps the prime consideration in this study, was consistently below that of the control group (Fig. 9). Angle collision experience also was

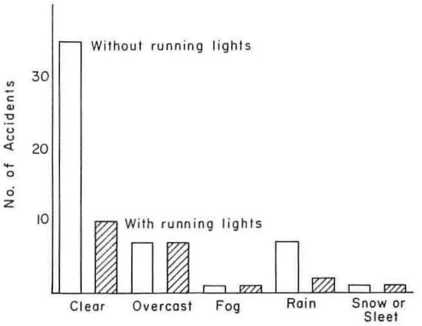

Figure 5. Accidents by weather conditions.

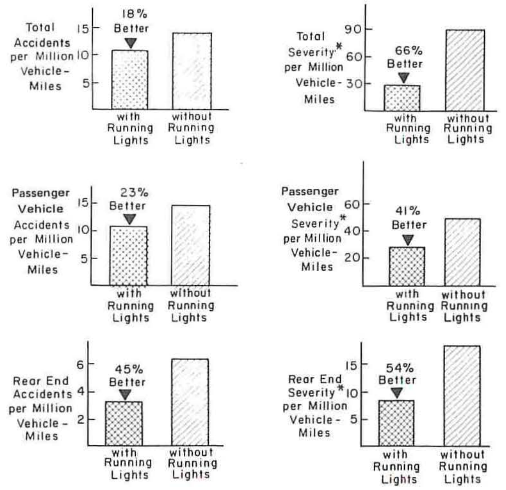

Figure 6. Accidents per vehicle-mile with and without running lights.

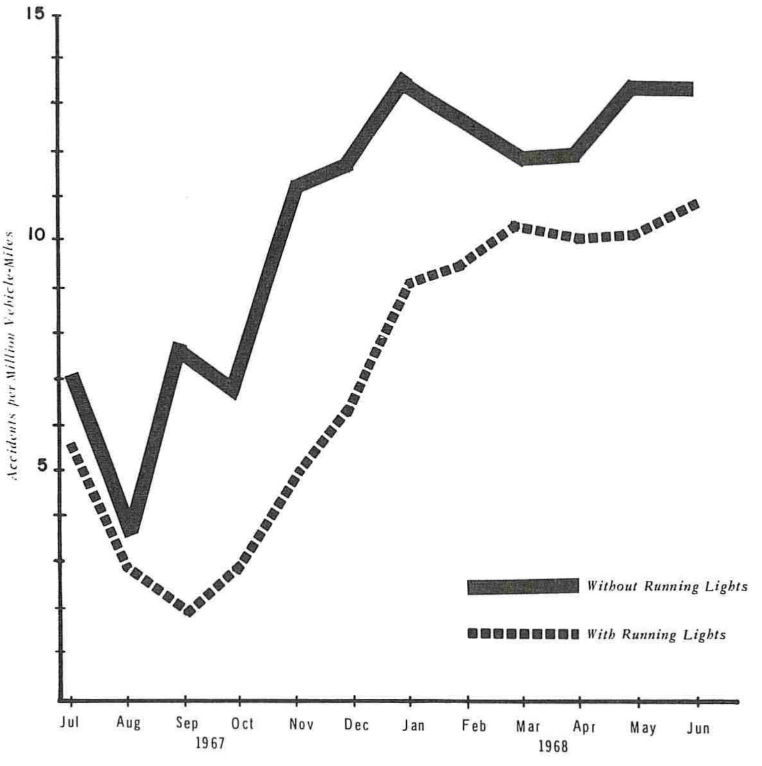

Figure 7. Cumulative monthly accident rate for all vehicles and all accidents.

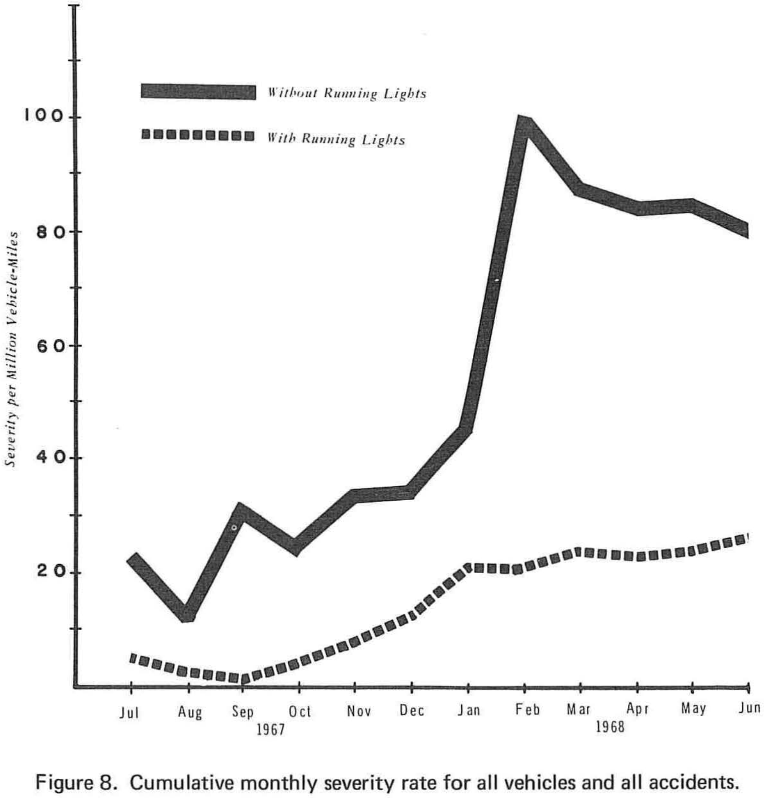

Figure 8. Cumulative monthly severity rate for all vehicles and all accidents.

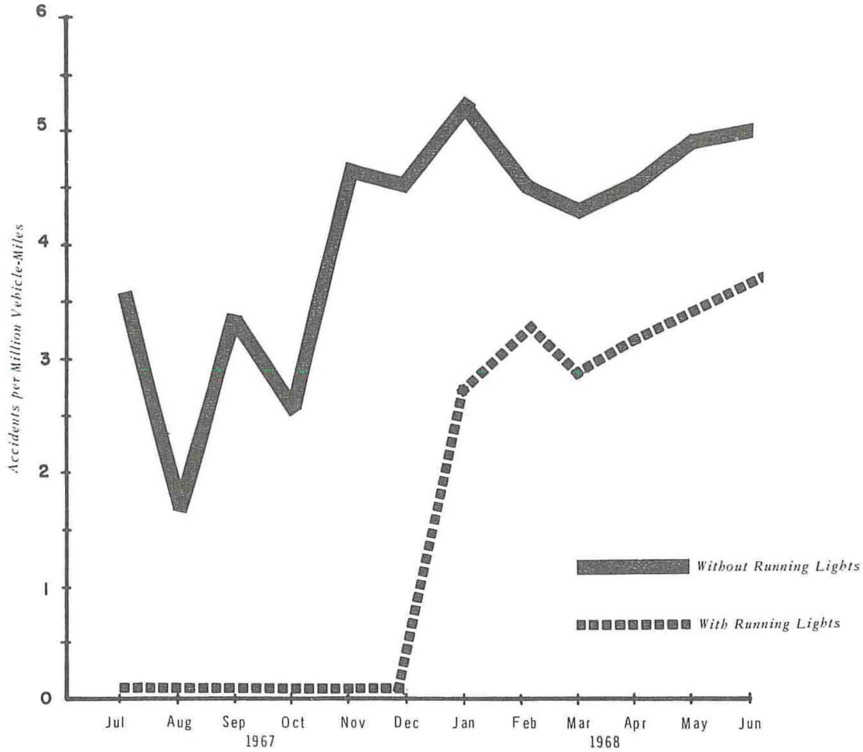

Figure 9. Cumulative monthly accident rate for all vehicles and rear-end accidents.

favorable to the modification after the first 2 months (Fig. 10). Backing accidents remained favorable, although the 2 categories approach each other's rates at the end of the test period (Fig. 11). Sideswipes, however, are quite unfavorable, although again the rates approach equalization and might equalize over a longer period of time (Fig. 12).

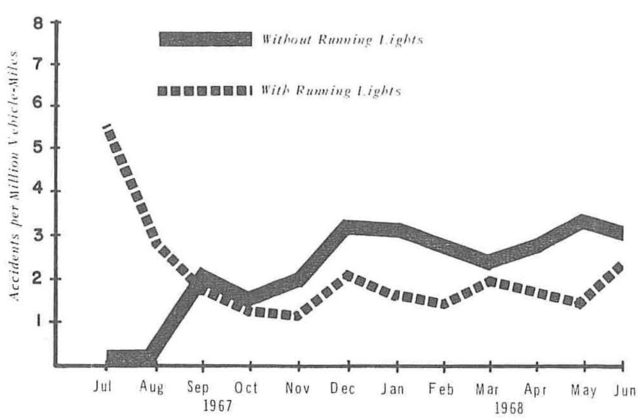

Figure 10. Cumulative monthly accident rate for all vehicles and angle accidents.

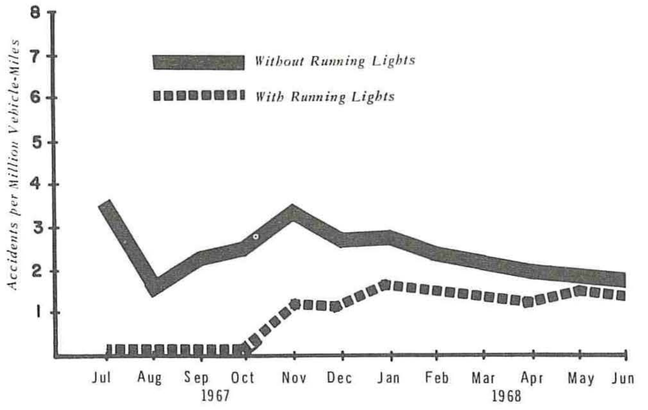

Figure 11. Cumulative monthly accident rate for all vehicles and backing accidents.

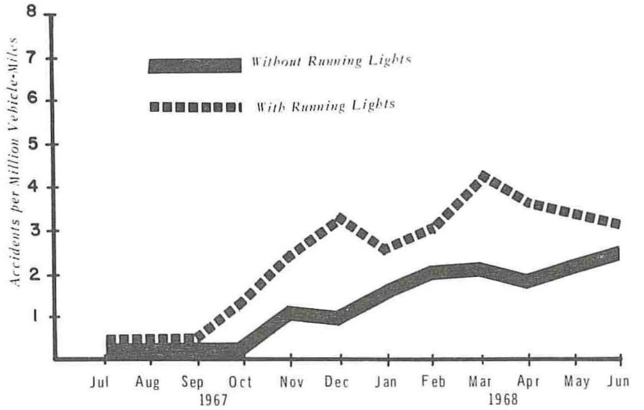

Figure 12. Cumulative monthly accident rate for all vehicles and sideswipe accidents.

Severity rates were not calculated for all vehicles because they represent essentially the rates for passenger vehicles (there were only 4 accidents for the modified trucks and 7 for the control groups of trucks).

Passenger vehicles only (all accidents) consistently showed favorable results for accident rate (Fig. 13), and striking results for severity rate (Fig. 14). The favorable result on overall severity of accidents is a very gratifying, if an unexpected, result of this study. Again, these differences are statistically significant.

The rear-end accident rate for passenger vehicles only shows the greatest effect of the running lights concept in this study (Fig. 15). Severity rate (Fig. 16) is again consistently lower. Although favorable, there is a tendency for both accident rate (Fig. 17) and severity rate (Fig. 18) of angle accidents to equalize toward the end of the study period. Backing accidents, as do rear-end accidents, show very favorable results both in accident rate (Fig. 19) and in severity rate (Fig. 20). Both accident rate (Fig. 21) and severity rate (Fig. 22) of sideswipe accidents show similar patterns quite the

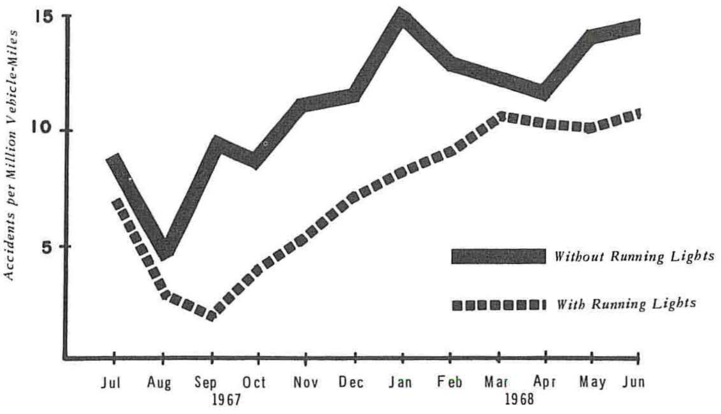

Figure 13. Cumulative monthly accident rate for passenger vehicles only and all accidents.

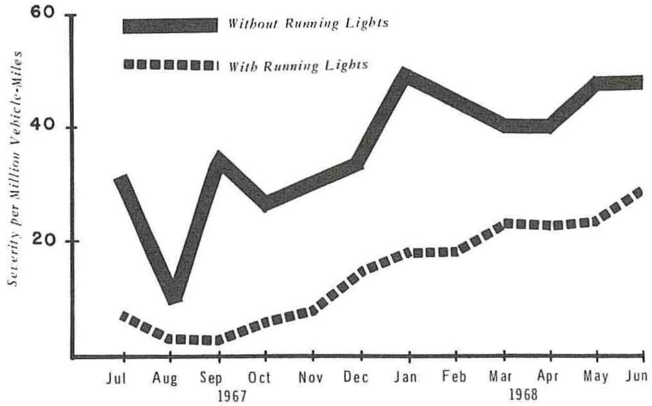

Figure 14. Cumulative monthly severity rate for passenger vehicles only and all accidents.

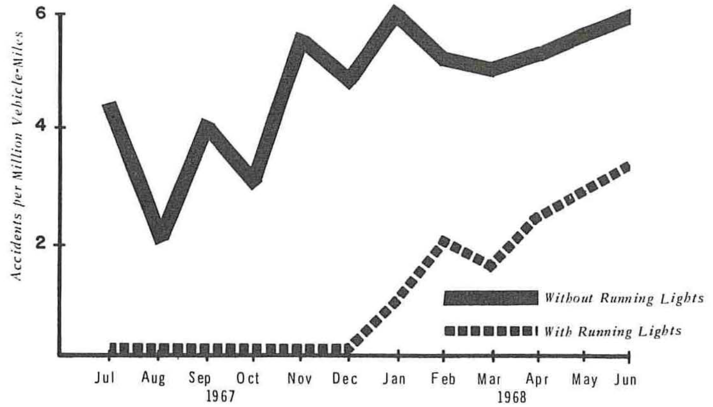

Figure 15. Cumulative monthly accident rate for passenger vehicles only and rear-end accidents.

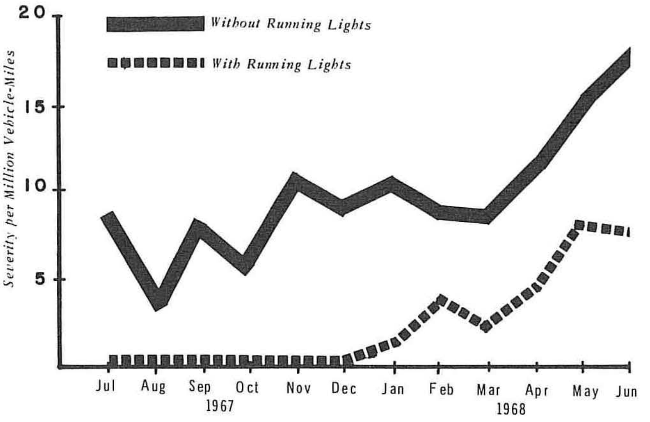

Figure 16. Cumulative monthly severity rate for passenger vehicles only and rear-end accidents.

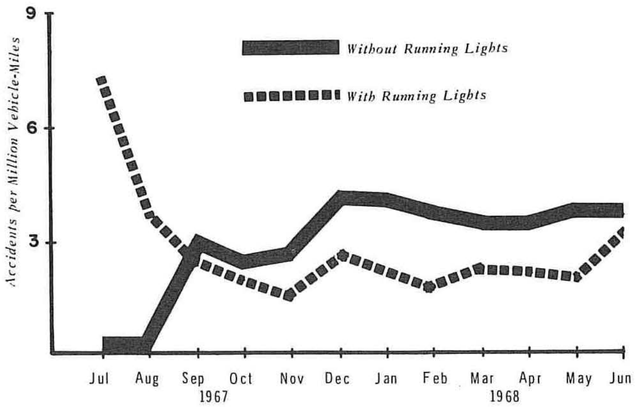

Figure 17. Cumulative monthly accident rate for passenger vehicles only and angle accidents.

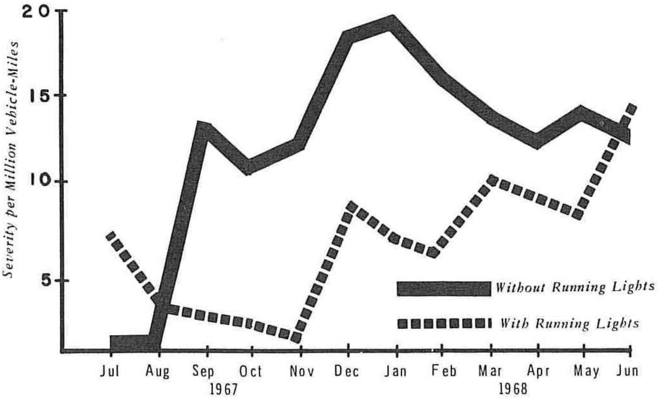

Figure 18. Cumulative monthly severity rate for passenger vehicles only and angle accidents.

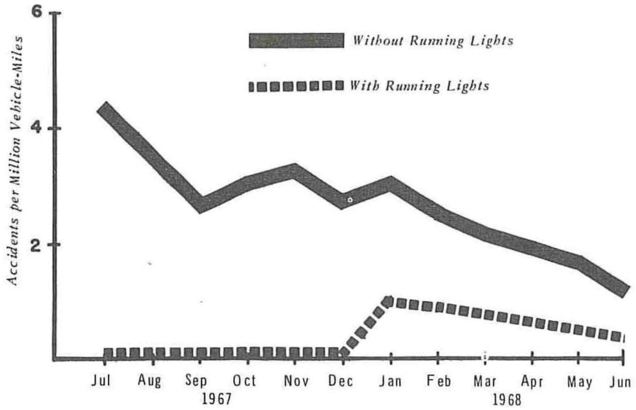

Figure 19. Cumulative monthly accident rate for passenger vehicles only and backing accidents.

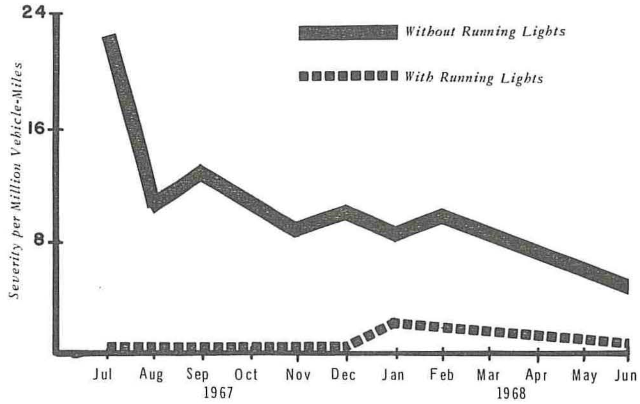

Figure 20. Cumulative monthly severity rate for passenger vehicles only and backing accidents.

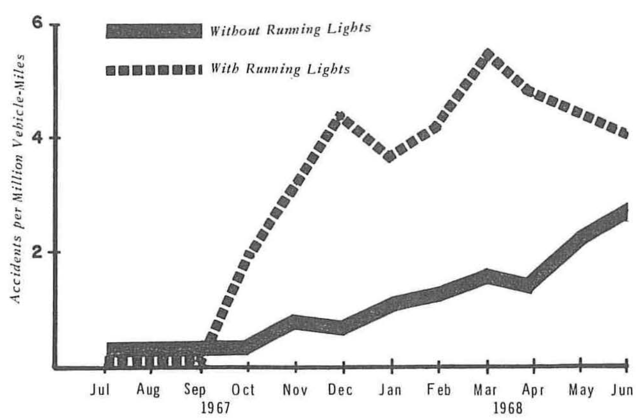

Figure 21. Cumulative monthly accident rate for passenger vehicles only and sideswipe accidents.

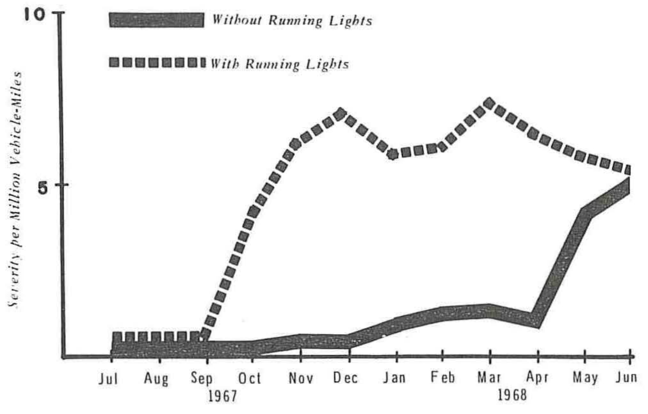

Figure 22. Cumulative monthly severity rate for passenger vehicles only and sideswipe accidents.

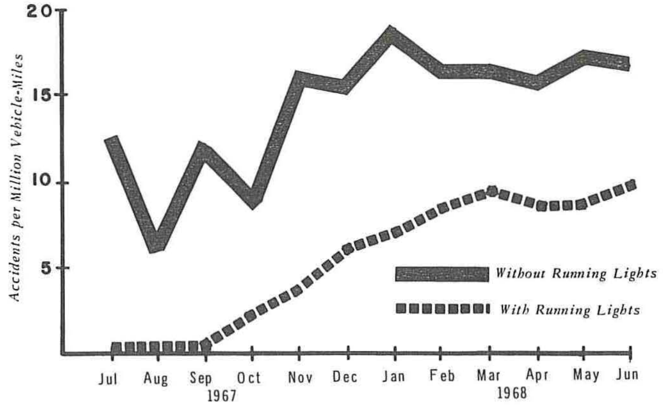

Figure 23. Cumulative monthly accident rate for black passenger vehicles only and all accidents.

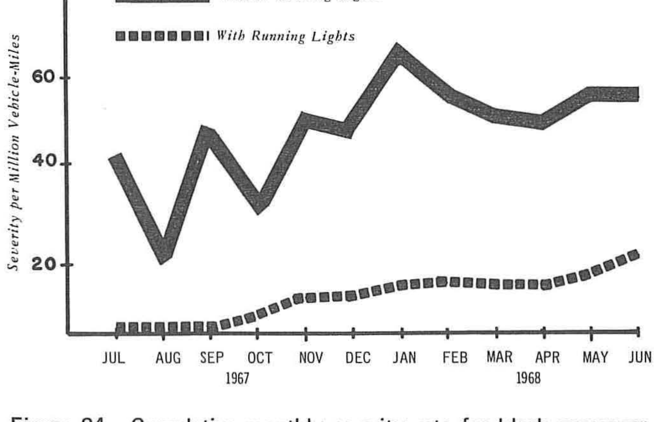

Figure 24. Cumulative monthly severity rate for black passenger vehicles only and all accidents.

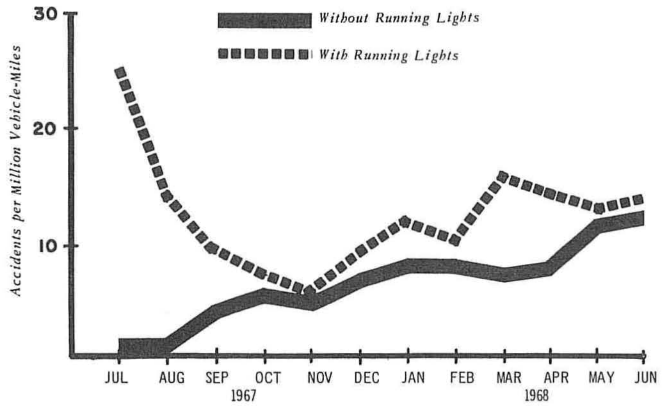

Figure 25. Cumulative monthly accident rate for yellow passenger vehicles only and all accidents.

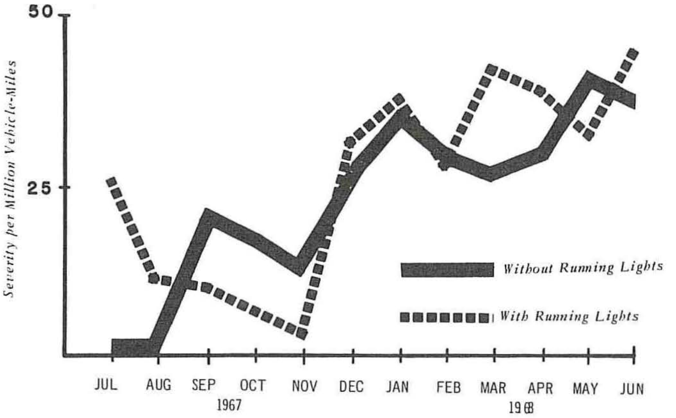

Figure 26. Cumulative monthly severity rate for yellow passenger vehicles only and all accidents.

reverse of experience for other accident types. No reasonable explanation for this experience is apparent. Both, however, approach identity at the end of the study. In the category of other vehicles only, differences in rates did not prove statistically significant.

For black passenger vehicles (all accidents), both accident rate (Fig. 23) and severity rate (Fig. 24) are most favorable to the running-lights concept. There are also statistically significant differences. There is no explanation for the results for yellow passenger vehicles (all accidents) except that there is less contrast between lights and vehicle color in daylight. However, the accident rate (Fig. 25) appears to approach identity, whereas severity rate (Fig. 26) fluctuates ambiguously. Statistically the differences here are not significant.

CONCLUSIONS

There is no doubt that the vehicles modified for running lights experienced a better accident history than those vehicles not so equipped. However, this experiment was

intended as a halfway measure to the testing of added running lights, as recommended by Allen and Clark. Therefore, even though the advantages of the simple system described in this paper (i.e., the use of parking lights and taillights as running lights) should be used on a larger scale (and the results thereof studied closely), the ultimate recommendation must be in the addition of lights to vehicles, most probably of a color differing from existing brake lights and parking lights, and also in the placing of lights on the vehicle so as to be visible at a greater distance (such as at the roof line).

It is apparent from the results of this study that the ambiguous results concerning yellow vehicles may suggest the observation made in certain studies that light-colored vehicles are inherently safer (or less accident-prone) than dark-colored vehicles. Conversely, the excellent results with black vehicles may be attributed to the excellent contrast of lights with the black background.

Other points of discussion or future study or both are suggested in the following questions: Is the disadvantage of taillights as running lights (being confused with brake lights) actually the underlying reason for the success of this experiment? That is, does the confusion of a driver behind such a vehicle lead to his maintaining a more respectful distance? Would the advantage of this conversion disappear if all vehicles were so modified? These questions, while deserving answers, are at this point academic. If a method or device is proved to be effective in accident reduction, it should be adopted until better proven methods are developed.

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Highway Environmental Safety Design Practices: A Topical Review

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Highways currently being designed and constructed contain safety hazards resulting from a lack of detailed information concerning some environmental features. A continuing study of all aspects of highway collisions is being conducted at the University of Utah in an effort to locate and define safety hazard areas in the vehicle, driver, and environment. Environmental roadway and roadside safety hazards in relation to longitudinal and cross-sectional elements are discussed from the collision causation and collision severity point of view. It was found that often the intent of safety standard suggestions was ignored in favor of strict standard adherence. It is concluded that a lack of communication exists between the highway designer and the safety researcher. It was also concluded that each highway must be designed with respect to the intent as well as the "letter" of suggested safety standards. The recommendation is made that a group of engineers and designers be created in each state for the purpose of coordinating and reviewing designs from a safety point of view. It is also recommended that this group review and make recommendations concerning severe collisions involving the environment on all roads within the state so that appropriate changes can be made.

•HIGHWAY SAFETY is commonly considered to be a function of the vehicle, the driver, and the environment. Currently, of these 3 interacting variables, only the vehicle is under strict regulation. Few specific regulations now exist for the driver or the roadway, but the National Highway Safety Bureau, U.S. Department of Transportation, among others, is carefully studying the contribution of the driver and the environment to highway safety.

The purpose of this paper is to evaluate some of the highway geometric considerations that affect traffic collisions from both the collision prevention and the collision severity point of view.

First, it should be pointed out that there is no such thing as a traffic "accident". Rather, there is a set of circumstances in the interaction of the vehicle, driver, and roadway system that creates a series of events during which a vehicle "collides" with another vehicle, a pedestrian, or the roadway furniture (i.e., guardrail, bridge abutment, and signposts). These circumstances, which could have been altered by changes in any one or any combination of the driver, the vehicle, or the environment, can not only contribute to the cause of a collision but also increase the severity of a collision.

Although a great deal of excellent research related to highway safety design has been conducted by both state and private agencies, much more is needed. One of the major problems facing the highway researcher and designer is the lack of available specific highway collision involvement detail.

The emphasis to date has been on the vehicle with little mention of the roadway other than brief comments in police reports and newspaper articles such as "the vehicle was flipped by the guardrail" or "the car ran off the road and hit a tree" or "the

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car crossed the median" or "the car traveled too fast on a curve" or "the car rolled over off the road". This type of description provides little useful information toward geometric design improvements.

In an effort to improve the knowledge of vehicle, occupant, and environment interaction, the University of Utah Collision Investigation Group is now completing the first phase of a continuing study of the contribution of the highway environment to collision causation and severity.

Since the introduction of the automobile, numerous studies have been made of individual geometric characteristics and their relationships to collisions. As early as 1937, Vey (16) suggested that highway design could eliminate 70 percent of all traffic collisions. Although this estimate may be high, it still remains that collisions and collision severity could be substantially reduced by proper highway design and construction. This has been demonstrated in part by the collision experience on the Interstate system. For example, Stonex (14) has pointed out that single-vehicle, run-off-the-road collisions involving 2 or more vehicles have been caused by 1 vehicle wandering from its specified path and intruding into the pathway of another, both at intersectional and nonintersectional locations. The fact is that even with research results available, such as those mentioned, many highways are still being constructed with inadequate attention being given to safety. The "cookbook" technique of safety design is too often followed, with no thought being given to the intent of the suggested safety design. Even the recommendations of the "Yellow Book" (6) have been ignored in many quarters. Many of these problems may be due to a lack of good communication within some highway organizations. Adequate safety design must rely on good communication for a properly coordinated effort.

For a more detailed examination of environmental factors contributing to or increasing the severity of collisions, the roadway will be separated into 2 broad classifications: longitudinal elements and cross-sectional elements.

LONGITUDINAL ELEMENTS

The most common longitudinal elements include tangents, horizontal curves, transition curves, and intersections. Historically the early road builders considered the tangent to be the ideal geometric design not only for ease of construction and right-of-way acquisition but also for safety, because curves were undesirable hazards for early motorists. Horizontal curves have long been considered a collision-producing feature, especially on the older rural secondary and primary system. Billion and Stohner (1) found that, on 2-lane highways with 20-ft pavements, curves greater than 5 deg had 4.35 times as many collisions as the average section of highway. On newer highways the design speed of the curves has been significantly increased with an accompanying reduction of the degree of curvature, thus the collision rate on curves has been decreased. Some comments on the interaction of tangents and circular curves will be made after the other longitudinal elements are discussed.

Unless the degree of curve is very small, a spiral or parabolic transition curve is generally used by most states to link the curve ends with the adjoining tangents. If transitions were not used in sharper curves, the driver would have to make abrupt steering corrections on entering the curve if he desires to maintain his lane position. Also, transitional curves prove useful in introducing superelevation, which will be discussed later.

Intersections can best be defined as points where merging, diverging, or crossing traffic streams interact. These include freeway interchange ramps as well as the common nonfreeway intersections. Intersections are always points of conflict and, as such, are high-collision-rate locations.

Ideally the driver should have to make only 1 decision at a time. If he has to make more than 1 decision, his efficiency decreases and more driver errors can be expected. Preliminary studies indicate that the merging and diverging of traffic at interchanges represents the weakest link in modern freeway design. The problem is further complicated by the fact that, while on-ramp collisions frequently involve 2 or more vehicles, many off-ramp collisions involve only 1 vehicle. These on-ramp, off-ramp

movements are so dissimilar that different studies of collision occurrence are necessary for each type. The freeway ramp location and design also have a profound effect on intersectional collision. Off-ramp gores that are hidden behind an overpassing structure, hidden out of sight over the crest of a vertical curve, or hidden around a curve by an embankment or structure are prime potential collision locations. Also, the ramp-end location with respect to grades is important.

Smith (15) located the ramp areas of highest collision frequency on vertical alignment. He found that the worst locations were just beyond the crests of vertical curves, because of poor sight distance, and near the top of an upgrade, because of reduction in acceleration ability of merging traffic. Another ramp location that is prevalent in many states is the left-lane or high-speed-lane entrance or exit ramp. In 1961 Fisher (4) showed that 6 left-hand ramps had considerably higher collision rates in all cases than comparable right-hand facilities. Yet left-hand ramps are still accepted design features in some states.

Careful consideration must also be given to ramp-end location with respect to other roads. For example, Figure 1 shows a situation where a freeway exit ramp butts head-on into the main road leading out of a small town. Several fatal head-on collisions have occurred downstream of this intersection in the last 6 years because drivers continued down the exit ramp onto the freeway in the wrong direction.

Figures 2 and 3 show another poor ramp location. When the freeway was constructed, the existing 2-lane roadway was converted into the eastbound freeway lane. As the freeway approached a small town, it veered to the south in a bypass maneuver. This allowed the existing roadway to be used not only for the eastbound lanes but also for the westbound exit ramp tangent to a circular curve in the westbound freeway lanes. This provided an economic advantage by eliminating the need for constructing a new ramp. The basic problem is that the westbound off-ramp is colinear with the eastbound freeway lanes. The visual impact of this situation is very evident in Figure 3. Note that even the directional sign upstream from the gore contributes to the visual impact by an arrow pointing straight ahead. Figure 4 shows the gore area. At this particular location the red WRONG WAY sign placed in the gore is completely hidden from view by a large reflector sign placed in front of it. Needless to say, wrong-way movements on the ramp are common at this location. Additional large WRONG WAY signs have recently been installed that should help. The ultimate solution, however, would be to move the ramp end northward to destroy the colinear effect. Because the right-of-way in this area extends 120 ft north of the existing ramp centerline, such an improvement would involve a minimum of effort.

Nonfreeway intersections come in such varied shapes and sizes that only a few comments can be made about them. The majority of nonfreeway intersections are either

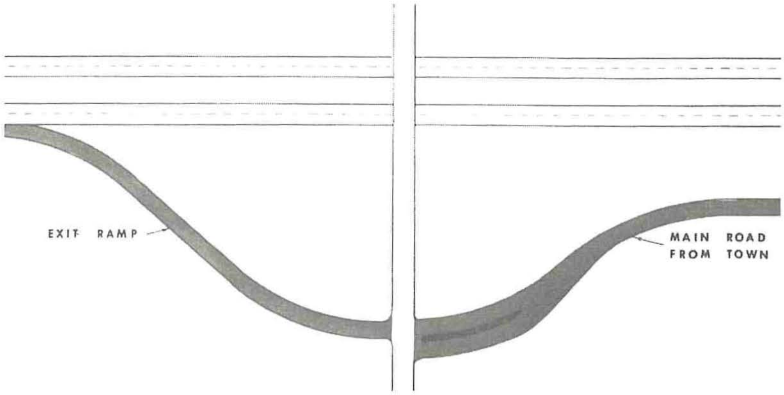

Figure 1. Poor exit ramp terminal location.

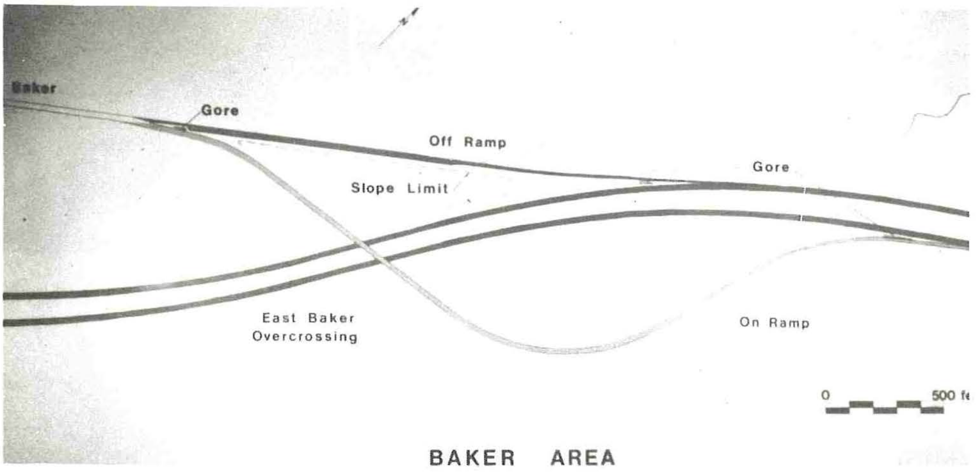

Figure 2. Plan view of the east Baker freeway interchange where existing roadway was used for the exit ramp.

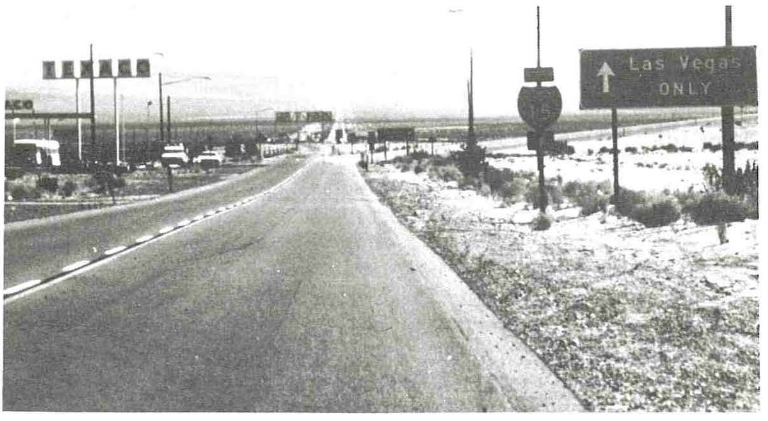

Figure 3. Visual impact of colinear effect of eastbound freeway lanes and frontage road near the east Baker interchange.

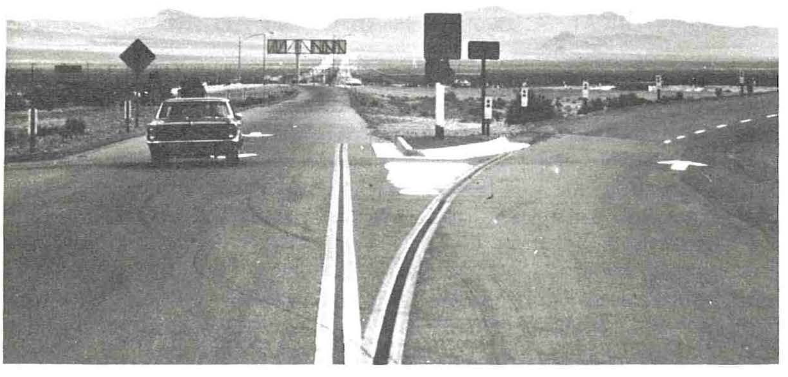

Figure 4. Gore area of east Baker interchange.

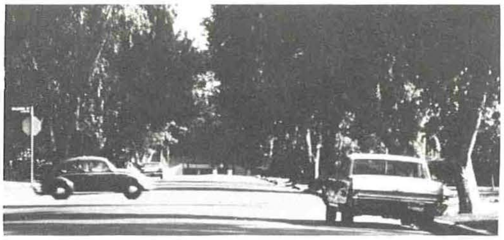

Figure 5. Intersection STOP sign hidden by a tree.

Figure 6. Intersection STOP sign after tree had been trimmed.

4-way or T-type. Marks (10), in a study of subdivision layouts comparing noncontrolled 4-way intersections with noncontrolled T-intersections, found a collision ratio of 14 to 1 for limited-access subdivisions and 41 to 1 for gridiron subdivisions. Other studies have shown similar results for arterial street intersections. The current study at the University of Utah indicates that, in many cases, at controlled intersections the control devices are partially or completely hidden by landscaping. Figures 5 and 6 show such a situation before and after a fatal collision. Before the tree was trimmed the STOP sign was not visible to drivers more than 60 ft from the intersection.

VERTICAL ELEMENTS

Now that the basic horizontal design elements have been described, vertical elements of grade and vertical curves should be considered.

It is important to consider grades and their impact on highway safety. Although our modern highways have stringent grade limitations, grade still plays an important role in collision causation. Bowman (2), in a study of collisions on the Ohio Turnpike, found that collisions were related to grade even though the upgrades were held to 2 percent and downgrades to 3.14 percent. Likewise, vertical curves have been cited as potential collision sources. Historically vertical curves have been prime collision locations because of the lack of sight distance. Even on modern freeways, with separated opposing traffic, vertical curves have high collision rates, particularly at intersections, as previously discussed. The presence of a very small and rapid succession of sag and crest vertical curves (roller-coaster effect) on secondary roads has proved to be an important hazard. If these rapid changes in grade occur at specific intervals, suspension systems at certain speeds can be excited that may lead to loss of steering ability resulting from long periods of front wheel unweighting.

LONGITUDINAL AND VERTICAL ELEMENT INTERACTION

Now that the basic longitudinal and vertical elements have been described, a review of their interaction will give a better insight into their relation with collision occurrence. The use of broken-back and compound curves is well known to be poor design practice. Both of these design types create undue stress on the driver by causing him to make steering corrections at a time when he may be unsure of this stability of the outcome. For example, the broken-back curve creates the need for a sudden change in direction. The compound curve can be an even more dangerous design feature because there is usually no advanced warning of a change in radius. Yet these geometric forms are still being constructed on the freeway system. Figure 7 shows a diagram of such a location on the Interstate system that is further complicated by entrance and exit ramps. This type of safety hazard must be recognized in the initial design phases and eliminated at that time.

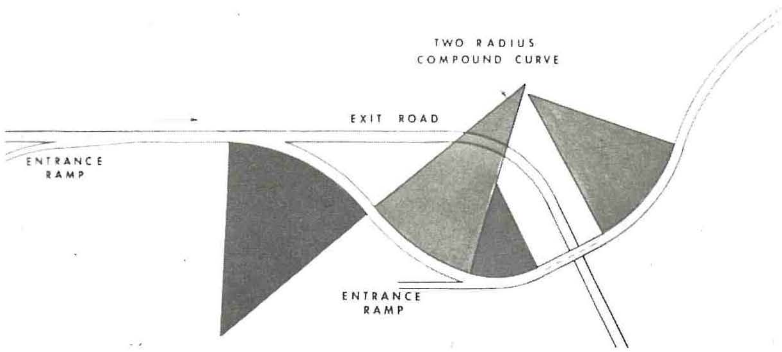

Figure 7. Multiple-curve design combined with entrance and exit ramps.

CROSS-SECTIONAL ELEMENTS

The collision potential of most of the longitudinal and vertical elements just discussed are fairly well known. The hard-line design of these elements can be readily checked by highway engineers for safety flaws. The effects of vertical cross-sectional elements on highway safety, however, are still relatively unknown as far as design is concerned. Moreover, cross-sectional design outside the shoulder is a virtually unknown design quantity from the safety standpoint. This is principally due to the lack of specific information about the roadside as mentioned previously.

Superelevation

First, the cross-sectional elevation characteristics of the roadway itself will be reviewed. In any discussion of superelevation, pavement crown must also be considered. Crown by itself has had little reported effect on collisions. When crown and superelevation interact, however, some safety questions arise. If the crown is phased out during the introduction of superelevation, proper drainage is preserved with a constant transverse slope. In some states, however, the crown is maintained through the transition and circular curve. This leads to slightly easier construction because the crown form would not have to be removed from the paver. The presence of a crowned section may create a problem in short-radius curves because only one point on the cross section would have the correct superelevation. If the curve is a right-hand curve and the crown is maintained throughout the curve, the high-speed left-hand lane that needs the maximum superelevation may not have it. Even though the limit of side coefficient of friction for the design speed would not be approached, the feeling of instability has been reported by drivers on such curves. This feeling of insecurity could lead to a driver error resulting in a collision.

Another possible problem with superelevation lies in its method of introduction. In the parabolic transition or circular curves with no transition, the superelevation is partially introduced in the tangent section. This forces the driver who wants to maintain his lane position to make a steering correction in the opposite direction of the upcoming curve. There is evidence that this type of maneuver on sharp curves has led to serious collisions.

Side Slopes

Side slopes and roadside elevation characteristics are highly variable even on the Interstate system. This roadside area has also been the focus of a great deal of attention recently because of the "clear roadside" campaign.

The suggested unprotected side slope on modern highways should not exceed 6 to 1. It is very easy to find side slopes that exceed this criterion. Figure 8 shows a high

embankment with a slope greater than 6 to 1. The token protection of the guardrail would be of little use to a vehicle running off the road upstream of the slope. Side slopes also have a first order influence on the probability of an out-of-control vehicle rolling over after leaving the roadway. Even though modern automobiles with their low center of gravity have a margin of safety with respect to stability, this margin can be quickly dissipated by surface roughness, softness, imbedded stones, tree roots or stumps, gulleys, and so forth, in addition to the grade of the side slope. Ideally, if not protected by barriers, the side slopes, drainage control, and roadside environment should be designed in such a way that a vehicle could traverse them without being tripped into a roll-over or stopped abruptly. The currently popular idea of maintaining a 30-ft-clear area is only valid in the absence of features that would encourage vehicles to venture further than 30 ft. For example, a side slope extending 30 ft would encourage a vehicle to travel down the slope beyond the 30-ft-clear area. If this fact is not taken into account in the design process, a situation similar to that shown in Figure 9 can occur. In this case the side slope is well designed and the 30-ft-clear area is maintained, but any vehicle leaving the roadway would be encouraged to continue into the trees at the bottom of the slope.

Figure 8. Inadequate side slope protection.

Shoulders

Shoulders, besides providing an emergency parking area for disabled vehicles, have been found to have an effect on collisions. Billion and Stohner (1) have shown the effect of shoulder width linked with a variety of alignments on a collision index. As a result of this and other studies, it has been suggested that shoulders on freeways be paved in order to provide a wide, firm surface for stopping. It has been indicated by experience, however, that paving the shoulder in the same material as the roadway surface may lead to some use of the shoulder for through traffic. This possibility could be reduced by edge-marking, coloring, or constructing the shoulder with different material than that used on the through lanes.

Lane Width

Historically the effect of lane width on highway safety has been studied. Lane width presents no real safety problem to freeways and new highways of all types built since the basic lane width used for design has been standardized at 12 ft. With the possibility of wider commercial vehicles, however, lane width may again become a primary safety consideration and should not be ignored.

Figure 9. Trees left at the base of a side slope.

Medians

Medians can best be defined as devices for separating opposing flows of traffic. The current Interstate design standard specifies a minimum median width of 30 ft with certain explicit exceptions. It is not uncommon to see medians less than 30 ft in width, however, even in rural areas. As would be expected, the cross-median collision rate goes down as the median

width is increased. Hurd (7) has shown that very few cars traverse a median 50 ft wide or wider. In urban areas where the median width decreases because of high right-of-way costs, median barriers have been successfully used to reduce the possibility of cross-median collision. On some of the older rural freeways this technique has also been used with success.

Each median situation should be considered separately during the design phase. For example, if 1 set of freeway lanes is located below the opposing lanes, a sloping median 30 ft wide may allow a high rate of cross-median events. In a situation such as this, the designer must use the minimum standards as an indication of intent rather than the hard design standards.

Right-of-Way

Right-of-way width is primarily important from a lateral obstruction standpoint. Historically there have been serious legal problems involved in having dangerous obstacles removed from private land adjacent to narrow rights-of-way, a situation generally typical of rural roads and many portions of the old primary highway system.

Lateral Obstructions

Lateral obstructions or highway furniture are perhaps the least understood and most important contributors to collision severity on modern highways. Lateral obstructions can best be defined as discontinuities in the cross-sectional surface. These discontinuities include control and information devices, highway service structures, nonhighway service structures, and the landscape. Stonex (13) has shown that a level obstacle-cleared roadside of approximately 33 ft would provide safety for at least 80 percent of the drivers leaving the road, and that a 50-ft obstacle-free roadside area would ensure safety for 90 percent of the drivers. As indicated earlier, rural roads and freeways are particularly susceptible to single-car, run-off-the road collisions. The roadside is one area where a great deal of detailed collision-involvement information is needed. Before better design standards are created, information must be obtained to indicate the types of discontinuities that are and are not acceptable.

Unfortunately, the bulk of the discontinuities, especially on freeways, are man-made and man-placed. These include control and information devices, highway service structures, and nonhighway service structures. Control and information devices can further be considered in 3 classes—regulatory devices, highway information devices, and additional information devices.

Signs

With the exception of pavement striping and channelization islands, most of the other control and information devices are supported on posts. These support posts may or may not look like barriers to an impacting vehicle depending on the size of the vehicle, the size and material of the post, the design of the support post and anchorage interface, and the speed at impact. Far too often on new freeways, signs are so large that heavy support post construction is necessary. Some effort has been made to protect vehicles from these posts by guardrail or other barrier installations. Extensive tests of breakaway poles (3) have been conducted at Texas A&M University, in cooperation with the the Texas Highway Department and the Highway Research Board. This work is well known, and the recommendations of these programs are now being applied widely.

Another consideration is the height at which signs, especially small signs, are attached to their supporting posts. Some evidence has been gathered indicating that small signs are breaking loose from their supports on impact and are penetrating the windshields of passenger cars, edge first. Also, if the support post breaks, the same phenomenon has been observed to occur, as shown in Figure 10.

Figure 11 shows another safety hazard that seems to be very common, even on the newest highways. Not only the vehicles being served by the type of sign shown in Figure 11 must be protected from the sign support, but also the vehicles traveling in the opposite direction. This is just another example of a case where safety design from

Figure 10. Small roadside sign that penetrated vehicle when struck.

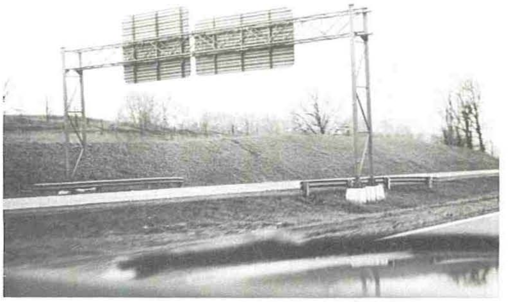

Figure 11. Sign bridge foundation exposed to opposing traffic.

the book was applied without consideration of the intent of the suggested standard.

Control and information devices ideally should be placed so that the driver is required to make only one decision at a time. Too often signs and signals are closely spaced or partially hidden, which forces the driver to spend more time looking for information and to make faster decisions, both of which may lead to a reduction in driver efficiency. Notation of spacing and distribution of signs is important to consider, particularly in freeway collisions where strangers are involved. The high rate at which information is transmitted to the driver on some highways makes it very difficult to perceive, analyze, and reject all of the unnecessary information. In a very short distance the driver can be exposed to regulatory controls consisting of signs, signals, channelization islands, and pavement striping as well as highway information devices consisting of signs of varying sizes and brilliance, and additional information devices such as billboards. In too many cases it appears that the Manual on Uniform Traffic Control Devices for Streets and Highways (9) is the most disregarded publication dealing with highway construction.

Barriers

With the possible exception of guardrails, highway service structures present the greatest hazard to single-car collisions. The design of bridges, bridge abutments, light poles, and drainage structures deserves much more consideration from the safety point of view.

Guardrails, where installed, have been effective in preventing impacts against highway structures as well as reducing cross-median events. However, guardrails have also been misused. One common misconception of guardrail use must be clarified before any meaningful discussion of guardrails can take place. Guardrails are not installed to protect roadside objects, as is often implied, but rather to protect vehicle occupants from possible serious injury due to vehicle impact with roadside objects. In order to justify the installation of a guardrail or other barrier, the severity of striking the barrier must be less than the predicted severity of hitting the obstruction from which the vehicle is being protected. Also, the type of barrier to be used must be considered carefully because a wide variety of barriers is available with differing characteristics.

The functional design of the barrier for each individual application is a necessary consideration. The bridge approach guardrail shown in Figure 12 would not be expected to redirect a vehicle properly, but would pocket the vehicle with subsequent possible barrier penetration. It the barrier is assumed to be strong enough to resist penetration, the basic problem is to prevent roll-over and provide redirection. This is principally a problem with W-section guardrail installed 24 in. high and attached directly to the supporting post. When a car impacts this type of installation, the supporting

Figure 12. Bridge approach guardrail installation.

posts begin to rotate, which effectively lowers the rail height and imparts, through the rotating rail, a rotating motion to the vehicle. The vehicle wheels also become entrapped in the posts and vehicle-tripping takes place. This primary rotation can be reduced by ensuring that the supporting posts do not rotate at initial contact. It can be accomplished by blocking out the W-section rail from the supporting posts. The resulting effect is that the blocks allow the rail to translate horizontally with little rotation. The possibility of vehicle-wheel entrapment is reduced by the offset or often by the use of a lower secondary rubbing rail. Eventually, the rail does begin to rotate, but, by the time the supporting posts do begin to rotate, the vehicle has traveled farther down the rail.

A secondary source of rotation comes from the car itself. If the moment between a low guardrail and a higher center of gravity is large enough to overcome the moment between the vehicle center of gravity and the wheel, then roll-over will occur. The best solution is to design the guardrail to contact the vehicle at a point near or ideally above its center of gravity. AASHO has suggested a guardrail design that meets this criterion. However, as mentioned earlier, each installation should be considered individually.

Cable-reinforced, chain-link barriers, if properly installed, have performed a reasonably effective job of reducing collision severity in California. The drawbacks of the cable-reinforced, chain-link barriers include the large amount of deflection room needed as well as the extensive repair costs. During a recent study, it was noted that the cable height of the reinforced chain-link median barrier tends to override the hood and contact the vehicle's A-pillar. If the vehicle remains in contact with the cable for more than 200 ft, there is a good chance that the A-pillar will saw through, allowing the cable to enter the vehicle. This phenomenon has been observed many times. Figure 13 shows an example of A-pillar damage.

Both the box-beam guardrail developed in New York and the New Jersey concrete median barrier have proved to be effective when installed in appropriate locations. Because each barrier design has its advantages and disadvantages, a variety of barrier systems should be available for use. This would allow the designer to specify the barrier best suited to any particular location.

Barrier-end treatment is also an important safety consideration. The need for strengthening guardrail ends to prevent excess deflection is well known. This has been most often accomplished by the "Texas twist" technique, and more recently the cable tie-down technique introduced by Nordlin, Field, and Folsom (12). These techniques will hold the rail end in place so that the rail will function properly near its ends and prevent the possibility of the rail end penetrating the vehicle occupant compartment.

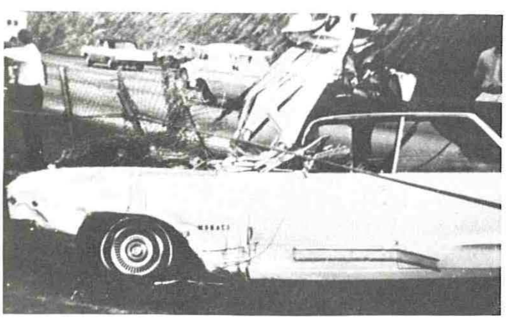

Figure 13. Vehicle underride of cable-reinforced, chain-link fence median barrier.

Collision testing of barrier-end treatments by Nordlin, Field, and Folsom (12) and Michie and Bronstad (11), among others, has indicated that barrier ends must be flared well away from the traveled way to prevent vehicles from striking the anchored ends with the resulting override or roll-over. Figure 14 shows a properly designed guardrail in which an end

Figure 14. Guardrail-end treatment.

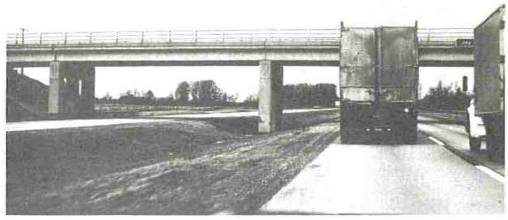

Figure 15. Exposed median bridge abutment.

anchor technique is used that disregards the necessity of being flared away from the roadside.

Roadside Objects

The remaining highway service structures of bridges, bridge abutments, light poles, and drainage structures provide favorite targets for run-off-the-road vehicles. Figure 15 shows a median bridge support that has no protection for vehicles placed around it. Moreover, the channel in the median tends to direct a vehicle into the support.

Drainage structures may be the greatest safety design offenders because of the frequency of their occurrence. The highway engineer has very sophisticated empirical techniques for determining the size and location of drainage needs. The interaction of these needs with safe roadside design, however, has been virtually ignored. Drainage ditch cross sections are often designed in such a way that a vehicle cannot traverse them. Culverts and headwalls are constructed as vehicle barriers rather than vehicle carriers. Erosion-control devices often become deep traps for vehicles, and many drainage ditches both at the roadside and in the median catch vehicles and lead them into other roadside obstructions such as trees, bridge abutments, or headwalls. Figure 16 shows a culvert headwall at the end of a drainage ditch. This headwall would act as a solid barrier to any vehicle that impacted it. Drainage structures can and should be designed so that they perform their drainage function and at the same time allow vehicles to traverse them safely.

Nonhighway service structures include utility poles and structures needed by various other forms of transportation such as railroad signals, airport approach lights, or elevated railway supports. Most railroad signaling devices are rigidly mounted near the traveled way and thus are often struck. Collisions at railroad crossings both with signals and trains account for 3 percent of all vehicle deaths (15). This fact has gained much attention recently from the National Highway Safety Bureau. The Interstate Highway System prescribes that there shall be no at-grade railroad crossings. Figure 17 shows that even on the Interstate system design standards are not always followed. Similarly the primary highway system has many hazardous railroad crossings hidden behind curves or, worse, located on curves that may lead to vehicle breakaway while cornering.

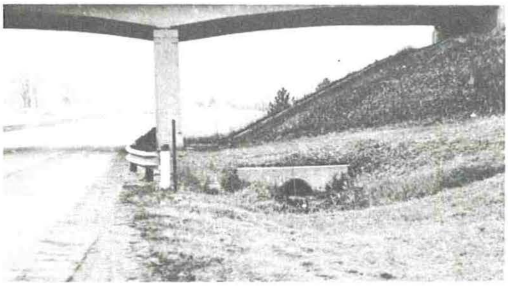

Figure 16. Exposed culvert headwall at the end of a drainage ditch.

Figure 17. Railroad crossing on the Interstate Highway System.

Figure 18. Large trees adjacent to a high-speed freeway.

Figure 19. Roadside lake and trees exposed to traffic.

Figure 20. Wide freeway median where trees have grown to a hazardous size.

Landscaping

Landscaping of interest includes the area adjacent to the shoulder or drainage structures and extends outward as far as vehicles may travel. Landscaping is an important feature of all roadways and can provide a pleasing atmosphere, be used as an indicator of direction, and perform a safety function by acting as a headlight glare screen or even as an energy-absorbing barrier. Too often, however, landscape features such as trees or large rocks become rigid roadside obstacles. Figure 18 shows a series of large palm trees, some located as close as 3 ft from the pavement edge. These trees, which were obviously planted in a roadway beautification effort many years ago, have now become lethal roadside obstacles.

Often the lack of landscaping or protection from natural landscape features creates a safety hazard. Figure 19 shows a lake adjacent to the Interstate system with no protective barrier. As a result several drownings due to vehicles running off the road and into the lake have occurred near this location. Figure 20 shows a freeway constructed approximately 25 years ago. At the time of construction the wide, flat median was void of any vegetation. During the ensuing years, a large number of trees have sprouted and grown to a size that constitutes a substantial roadside hazard.

CONCLUSIONS

The intent of the preceding remarks has been to indicate some of the environmental problem areas contributing to highway collision causation and severity that are not often mentioned. Unfortunately, some of these areas are frequently ignored during the design and construction of highway facilities. It is encouraging, however, that an ever-growing compilation of safety design guidelines, including such items as the Yellow Book (6), the National Cooperative Highway Research Program Report 54 (8), the Handbook of Highway Safety Design and Operating Practices (5), and many other individual reports are being used by many design engineers.

The real problem seems to be one of communication, not only between the highway departments' researchers and interested citizens but also within the highway departments themselves. Also communication or "check-back" between operating and design departments is necessary for proper safety design. For example, until recently there seems to have been little communication between bridge design sections and highway design sections concerning the interface of the bridge rail abutment with the rest of the environment. Strong efforts are needed to improve such communication.

The operation of the spot improvement program has been discussed elsewhere (17). The spot improvement program should be only a part of any highway department's safety effort, but in several states it is the only program. The goal should be to design and build safe highways initially so that the spot improvement program would be "designed out of business".

To achieve this goal, each highway department or agency should have a group of engineers and designers whose sole function is to keep abreast of the latest safety design features and to ensure that all highway plans incorporate these features. It is also recommended that this group review all severe collisions involving the highway or the surrounding environment before repairs are made so that necessary safety improvements can be recommended. This should not only be done for the primary state, federal, and Interstate Highway Systems, but also for the county road systems on a free consulting basis. The adoption of such a program would lead to safer highway environments.

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The Safety Index: A Method of Evaluating and Rating Safety Benefits

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•EACH YEAR the California Division of Highways prepares a planning program, which is basically a schedule of the funding of major construction projects for the next 8 to 11 years. It shows the amounts and the fiscal years of funding for construction and right-of-way acquisition for 2,500 to 3,000 projects costing more than $100,000 each. The 1969 program totaled $7.8 billion.

Every attempt is made to schedule the most needed projects first. There are many constraints operating to limit or to modify the scheduling of construction projects strictly on congestion or safety priority considerations. Some of the constraints are statutory (see Appendix), and others are imposed by difficulties in obtaining necessary freeway, railroad, or cooperative agreements and route adoptions. Another major constraint is the requirement of completing the Interstate system by a given time. Within these constraints, however, there still is a great deal of flexibility to program by traffic-related priorities.

Factors considered in determining relative priorities of the many competing projects include congestion, delay, accident rates, fatality rates, types of accidents, closing gaps in the highway system, continuity of improvement, coordination with local development, impact on local communities, and relocation impact on economically deprived areas.

To determine priorities objectively, it is desirable to quantify the benefits of each project (e.g., hours of congestion reduced, vehicle-hours of delay reduced, number of accidents prevented, and number of lives saved) and relate these benefits to the cost of obtaining them. Historically, the classical tool that has been used to make economic evaluations on route location selection, and that also could be used to establish relative priorities of projects, is the benefit-cost ratio. This ratio is based on the dollar savings accrued to the road user because of reduced travel times, distances, and operating costs.

A few years ago, the California Division of Highways developed a new tool to evaluate safety improvement projects—the safety index. The safety index represents the percentage of the project's construction plus right-of-way costs that is returned to the motorists as savings in the cost of prevented accidents. In reality, it is a safety benefit-cost ratio. The decimal point has been moved to the right 2 places, and the ratio is called an index.

In the 1969 program, for the first time, we have extended the use of this tool to all major construction projects. For each project an estimate was made of the number of accidents that will be prevented by the proposed improvement and of the cost savings resulting from the accident reduction. The savings, expressed as a percentage of the cost of providing the improvement (construction plus right-of-way), is the project safety index.

METHODOLOGY

To predict the savings in accident costs to be accrued, we must estimate the number and cost of accidents that will occur if no improvement is made and the number and cost of accidents that will occur if the improvement is made.

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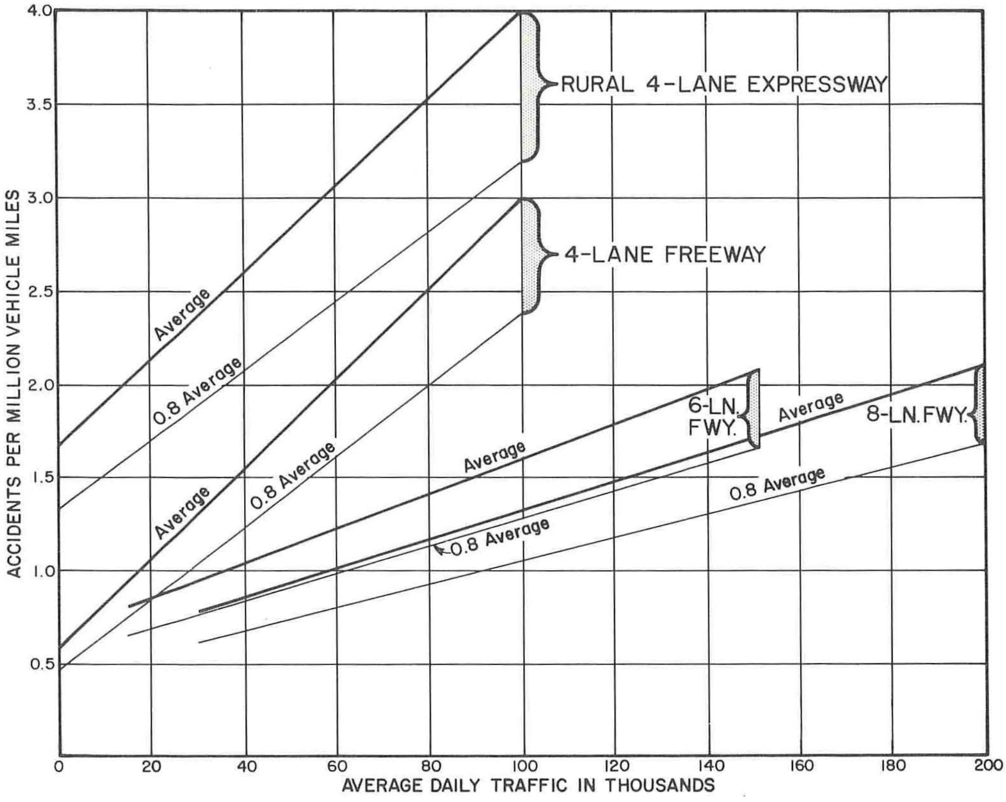

Figure 1. Accident rates for freeways and expressways with varying numbers of lanes.

Studies over the past few years have developed predictive models to estimate accident frequency. The models are sophisticated enough to account for the effect of the number of lanes and traffic volumes on accident rates for all types of freeways (7) and also for rural expressways (Fig. 1). Models also have been developed for various types of spot-improvement projects such as channelizing, guardrailing, signalizing, safety lighting, and signing (2, 12, 13, 14, 15). However, the correlation of certain accident causative variables such as pavement width, number of lanes, and traffic volumes on accident frequency on conventional roads remains to be accomplished. For new conventional roads, the rates given in Table 1 are used. For existing conventional highways, the accident rate of the segment under consideration is used, if it is the best

TABLE 1

STATEWIDE ACCIDENT RATES (1966-68 AVERAGE)

Highway Type	Rural		Urban	
	Statewide Average	0.8 Value	Statewide Average	0.8 Value
2-lane conventional	2.50	2.0	5.35	4.3
2-lane expressway	1.70[a]	1.4	2.74[a]	2.2
3-lane conventional	2.91	2.3	5.38	4.3
4 or more lane undivided	3.55	2.8	6.15	4.9
4 or more lane divided	2.53	2.0	5.30	4.2
Divided expressway	(see Figure 1)		3.50	2.8
Freeway	(see Figure 1)			

Note: Rates are total accidents per million vehicle-miles.

[a]1968 average rate only.

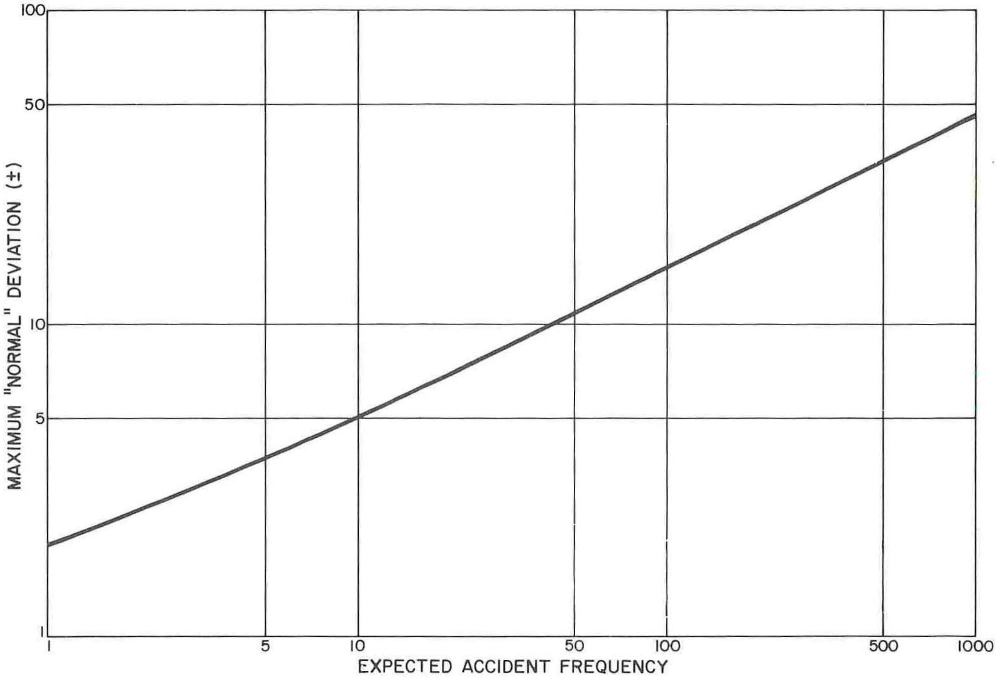

Figure 2. Maximum expected deviations at 85 percent confidence level.

estimate that can be made. Using the existing rate almost always understates the benefits. The reason is that the rate probably increases as traffic volumes increase. Unfortunately, we do not know how much the increase will be.

Adjusting for Accident Severity

Before estimating accidents that would occur on the existing facility with no improvement, a statistical test (16) is made of the severity distribution of the accidents occurring over the past several years on the existing road. If the distribution is normal, or approximately so, the average cost of accidents for that road type is used. If, however, the accidents are more severe than normal, a higher accident cost is used to reflect the higher costs of fatal and injury accidents. Conversely, if the accidents are less severe than usual, a lower cost is used. In this manner, considerably more weight is given to the fatal and injury accidents than to the "fender benders."

For instance, the reported accidents on most rural freeways in California are composed of about 4 percent fatal, 43 percent injury, and 53 percent property-damage-only accidents. We have developed a curve (Fig. 2) that indicates, for any given accident sample size, how much variation there must be between the observed and expected distribution of severities to be statistically significant. This curve is based on the Poisson distribution, at the 85 percent confidence level, and is another form of the "liberal test" curve shown in Figure 3 of the Morin report (16). For instance, if in 100 accidents on a rural freeway there are 6 fatal accidents instead of 4, are the 6 fatal accidents really different from the expected 4 or are they merely a reflection of the usual statistical fluctuations in accident frequency? Figure 2 shows that with an expected frequency of 4 accidents, an actual occurrence of 1 to 7 is "normal." Therefore, the 6 is not abnormally high. If there had been 8 fatal accidents out of the 100, then it could be said with reasonable assurance that this is not a chance occurrence but that 8 fatal accidents occurred because there is something especially hazardous about this section of road.

TABLE 2

COSTS BY ACCIDENT SEVERITY

Highway Type	Fatal	Injury	Fatal and Injury	Property Damage Only	Total
Rural					
2-lane	95,000	3,000	8,800	1,000	4,600
3-lane	95,000	3,000	10,500	1,000	5,000
4 or more lane undivided	95,000	3,000	6,700	1,000	3,400
4 or more lane divided	95,000	3,000	7,800	1,000	3,900
Divided expressway	95,000	3,000	9,500	1,000	4,800
Freeway	95,000	3,000	10,100	1,000	5,300
Urban					
2-lane	76,000	2,400	4,000	700	1,800
3-lane	76,000	2,400	4,800	700	1,900
4 or more lane divided	76,000	2,400	3,700	700	1,700
4 or more lane undivided	76,000	2,400	3,700	700	1,700
Divided expressway	76,000	2,400	4,900	700	2,300
Freeway	76,000	2,400	4,300	700	2,200

Accident Costs

The average accident costs given in Table 2 are based on the normal distribution of severities given in Table 3. When the fatal, injury, or fatal-plus-injury category is abnormally high or low in frequency, it is necessary to determine a specific "average" cost for the distribution observed. The specific average cost is determined by summing the products of each accident severity category frequency by its specific unit cost and dividing the total accident cost by the sum of all severity frequencies. For instance, if a section of rural freeway has experienced 200 accidents, of which 16 are fatal accidents, 120 are injury accidents, and 64 are property-damage-only accidents, the specific average cost of these accidents is

$$16 \times \$95{,}000 + 120 \times \$3{,}000 + 64 \times \$1{,}000/200 = \$9{,}720$$

For new highways, it is assumed that the accident severity mix will be normal. Usually there is no reason to assume otherwise.

TABLE 3

PERCENTAGE DISTRIBUTION BY ACCIDENT SEVERITY

Highway Type	Fatal	Injury	Fatal and Injury	Property Damage Only	Total
Rural					
2-lane	2.9	43.0	45.9	54.1	100.0
3-lane	3.4	38.7	42.1	57.9	100.0
4 or more lane undivided	1.7	39.7	41.4	58.6	100.0
4 or more lane divided	2.2	39.8	42.0	58.6	100.0
Divided expressway	3.2	42.0	45.2	54.8	100.0
Freeway	3.6	43.2	46.8	53.2	100.0
Urban					
2-lane	0.7	31.0	31.7	68.3	100.0
3-lane	0.9	28.4	29.3	70.7	100.0
4 or more lane undivided	0.6	33.8	34.4	65.6	100.0
4 or more lane divided	0.6	31.5	32.1	67.9	100.0
Divided expressway	1.3	35.6	36.9	63.1	100.0
Freeway	1.1	40.7	41.8	58.2	100.0

Accident costs are based on studies made in Washington, D. C., and by the Illinois Division of Highways, and the California Division of Highways (11). They include present worth of future earnings of persons killed or permanently disabled. They have been adjusted upward in the case of injury and property damage accidents to reflect unreported accidents (10), so that when reported accidents are multiplied by these unit costs the total cost of both the reported and the unreported accidents is obtained. The cost values have also been updated to 1969 prices.

Project Costs

For project cost, only the unbudgeted and unescalated construction and rights-of-way costs are used. Funds already expended or obligated are sunk costs and should not be considered in deciding how to make future expenditures. Today's cost is used even though future project costs will escalate at an average rate of 3 percent per year for construction and 5 percent per year for rights-of-way. This is done for 2 reasons. First, the costs of future accidents are not escalated; and, second, we determine the safety index on the basis of all projects being opened to traffic the following year by which time costs will have increased only slightly.

Traffic Volume Considerations

The number of accidents that will occur is predicted by multiplying an accident rate by the predicted vehicle-miles of travel. In most cases, the travel that would occur on either the existing road without improvement or on the improved road is the same. However, in some cases the predicted future traffic volume exceeds the capacity of the existing highway, reducing travel on the existing highway in relation to the improved road.

If the predicted traffic volumes exceed the capacity of the existing state highway but the adjacent local streets can handle the overflow, the number of accidents that will occur in the case of no improvement is the number of accidents that will occur on the existing state highway with the capacity constraint plus the additional accidents on the local streets caused by the overflow. The accidents that will occur on the existing state highway are computed by multiplying its accident rate by the vehicle-miles of travel that will be generated on it with the capacity constraint. The additional accidents on the local street system are determined by multiplying the local street accident rate by the overflow vehicle-miles from the state highway. (When the local street accident rate is not readily available, the statewide average rate for state highways of the same type is used.)

When the existing highway and all local streets cannot handle the projected traffic volumes, it is assumed that the travel over and above the combined capacity of the existing highway and street system will not occur.

"Capacity" as used previously refers to the greatest possible volume of traffic without regard to level of service. In fact, it means an intolerable level of service with long daily periods of extreme congestion and delay. Although a highly undesirable state, it may very well result if no improvement is made, and this analysis is based on the safety benefits that would accrue between no improvement and the proposed improvement.

TABLE 4

CAPACITY TRAFFIC VOLUMES

Type of Facility	Maximum AADT
2-lane conventional or expressway	24,000
3-lane	30,000
4-lane conventional, divided or undivided	50,000
6-lane conventional, divided or undivided	75,000
4-lane expressway	60,000
6-lane expressway	90,000
4-lane freeway	90,000
6-lane freeway	150,000
8-lane freeway	220,000
10-lane freeway	300,000

Capacity values used for safety index determinations are given in Table 4. These volumes have actually been observed on several occasions and may be lower than can possibly occur.

Base Year and Project Life

For programming purposes, the safety index is computed as if all projects were

opened to traffic the same year (1970 for the 1969 planning program). The reason is that the index should indicate relative safety priorities. Different base years falsely magnify the benefits of projects that will be constructed in the later years because of the larger number of accidents reduced because of increasing traffic volumes. Once programming has been established, an index based on the actual year of opening gives the real benefits that will accrue. Management, however, is interested in knowing the safety index before priority of construction has been determined so that relative benefits among projects can be evaluated to establish the priority of construction.

Project life is the number of years the improvement will be used by the motorist regardless of what governmental subdivision will have jurisdiction. A maximum of 20 years is used because of the many uncertainties when dealing with predictions too far in the future. "Interim" improvements that will continue to serve the motorist after the highway is relinquished by the state have a life-span reflecting their continued use under the local government. (After relinquishment, the existing highway may carry less traffic and its vehicle-miles of travel should be based on the reduced traffic.) Generally, a service life of less than 20 years is used only when the existing roadway will be physically obliterated.

PREDICTING ACCIDENT RATES

New Highways

Figure 1 shows the accident rates for new freeways and rural expressways. These rates are statewide averages for facilities ranging from good to poor compared to present standards. New highways should have considerably lower rates and therefore the 0.8 statewide average is generally used.

Figure 1 shows the effect of traffic volumes on accident rates on freeways and rural expressways. Similar effects probably exist for all highway types, but the effects have not been quantified satisfactorily. (There is research under way in this area.) Therefore, 0.8 statewide average accident rates, disregarding volume effects, are used (Table 1). Again, new conventional roads should be safer.

Where the new facility will be constructed to low standards, average (in lieu of 0.8) values should be used, e.g., a mountain highway with minimum alignment standards.

Future Rates for Existing Highways

To estimate what the accident rate will be on an existing freeway or rural expressway at a future higher traffic volume, we assumed that the future accident rate will bear the same relative relationship to the statewide average for the new traffic volume as the present rate bears to the statewide average for the present traffic volume. For instance, if the rate today is 50 percent higher than the statewide average, the accident rate will continue to be 50 percent higher than the average as traffic increases. An example is given in the following:

4-Lane Freeway	Today	Future
ADT	25,000	40,000
Accident rate	1.60	?
Statewide rate	1.18	1.54

$$\text{Future rate} = (1.60/1.18) \times 1.54 = 2.09$$

The preceding methodology applies to all freeways and rural expressways (not urban expressways). For other existing roads, the future accident rate is assumed to be the same as the current rate regardless of traffic increases.

Widened Highways

Judgment must be used in selecting future accident rates for existing facilities that are being widened.

When lanes are added to a freeway without geometrics being improved, the only accident reduction to be expected results from reduced lane densities (as reflected by the

family of curves in Figure 1). In this case, it can be assumed that the accident rate of the widened freeway will be a given percentage of the rate it would have experienced without widening at the predicted traffic volumes. The "expected" rates are approximately as follows:

Existing	Proposed	New Rate
4-lane	6-lane	60 percent of 4-lane
4-lane	8-lane	50 percent of 4-lane
6-lane	8-lane	80 percent of 6-lane
6-lane	10-lane	75 percent of 6-lane
8-lane	10-lane	90 percent of 6-lane

For instance, the same 4-lane freeway in the earlier example that has a predicted rate of 2.09 accidents per million vehicle-miles at 40,000 ADT would have a rate of $0.60 \times 2.09 = 1.25$ if widened to 6 lanes and $0.50 \times 2.09 = 1.05$ if widened to 8 lanes.

If this same freeway were upgraded to current standards as well as widened, the new accident rate can be read off Figure 1 (0.8 line) directly: 0.83 for 6 lanes and 0.68 for 8 lanes.

Occasionally highways are improved in stages. For instance, a 2-lane road is improved to a 4-lane freeway as the first stage and widened to 6 lanes as a second stage 10 years later. In such a case, the "existing" (no improvement situation) accident rate for the second stage widening project is the accident rate predicted for the 4-lane freeway of the first stage.

Summary of Rate Predictions

Tables 1 and 5 give criteria for predicting accident rates. Notice in Table 1, for example, that the accident rate of 2-lane conventional roads is less than corresponding rates for roads with 3, 4, or more lanes. This is so not because 2-lane roads are

TABLE 5

METHODOLOGY SUMMARY FOR ESTIMATING FUTURE ACCIDENT RATES

Type of Facility	How to Predict Future Accident Rate
Existing conventional highway and urban expressway	Current rate of existing highway
Existing rural expressway	New rate = $(A/B) \times C$[a]
Existing freeway	New rate = $(A/B) \times C$[a]
New conventional highway and urban expressway	0.8 of latest statewide 3-year average (Table 1)[b]
New freeway and rural expressway	Figure 1 0.8 rate values[c]
Widened freeway	
4 to 6 lanes	60 percent of expected rate for 4 lanes[d]
4 to 8 lanes	50 percent of expected rate for 4 lanes
6 to 8 lanes	80 percent of expected rate for 6 lanes
6 to 10 lanes	75 percent of expected rate for 6 lanes
8 to 10 lanes	90 percent of expected rate for 8 lanes
Shoulder widened on conventional highway	0.8 to 1.0 of statewide average (Table 1)
Widened conventional highway 2 lane to multilane	0.8 to 1.0 of statewide average (depending on standards proposed) for type of multilane proposed

[a] A = current accident rate; B = statewide average rate for current ADT; and C = statewide average rate for future ADT.
[b] If new facility is to be constructed to less than current standards, use 1.0 of latest statewide rates.
[c] If new facility is to be constructed to less than current standards, use 1.0 rate value in Figure 1.
[d] Expected rate calculated as for existing rural expressway and freeway.

safer but because they have much lower traffic volumes, fewer cross streets, lower volume cross streets, and less roadside development.

Using statewide rates will sometimes give grossly erroneous results. For instance, an existing rural 2-lane road with an accident rate of 2.6 being widened to a 4-lane undivided road would have an indicated accident rate of 3.5 when, in fact, the rate should decrease. Unfortunately, until ongoing research on accident rates for conventional roads is completed, it is not known how much the accident rate should decrease. In cases such as this, it is not possible to determine an accurate safety index.

MINIMUM SAMPLE SIZE

Accidents are statistically rare and random events. Accident frequency and consequently accident rates are subject to statistical variations. With small samples, say less than 25, the percentage variations can be very large, giving unreliable accident rates on the existing road to extrapolate into the future.

There are ways to compensate for small sample size. One method is to extend the time period. In so doing, it is important that there be no substantial highway or environmental changes during the extended period. (This constraint applies regardless of the period of time.) A second method is to use the average rate of a longer section of similar and contiguous highway. In the following example, it is more accurate statistically to use the average rate of combined Projects A, B, and C (2.50) for each project rather than the individual rates.

Project	MP/MP	Number of Accidents	Accident Rates Actual	Accident Rates Use
A	0.0/3.0	7	1.95	2.50
B	3.0/6.5	13	3.10	2.50
C	6.5/10.0	10	2.38	2.50
A, B, C	0.0/10.0	30	2.50	2.50

In the preceding example, it really is not known which section is best or worst; and, therefore, it is assumed all 3 are the same.

TYPICAL APPLICATIONS

Two examples follow outlining how the safety index is determined.

Major Construction Project

A conventional 2-lane rural road is to be converted to a 4-lane freeway at a cost of $8,600,000 (unbudgeted construction plus unbudgeted right-of-way). The 1970 traffic is 11,500 vehicles per day, and 29,000 is predicted in 1990. Capacity of 24,000 vehicles per day of the 2-lane road is reached in 1984. No other parallel local road exists or is planned because the existing state highway crosses a marshy tideland.

The travel that will occur with and without the freeway construction and the observed and expected accident frequency for the past 3 years is shown in the following example of an existing 2-lane highway, 6.9 miles long, proposed to be improved to a 4-lane freeway, 6.5 miles long. The construction and right-of-way costs (unbudgeted) is $8.6 million, and the project life is 20 years. Traffic data are as follows:

Item	No Improvement	With Improvement
Vehicles per day		
1970	11,500	11,500
1984	24,000[a]	—
1990	24,000[a]	29,000
Vehicle-miles generated	987,000,000	958,000,000

[a]Capacity of 2-lane road; no alternate routes available.

The accident experience for the past 3 years is as follows:

Accident Severity	Observed[a]	Expected[a]	Significant[b]
Fatal	14	3.6	Yes
Injury	48	52.9	No
Fatal and injury	62	56.5	No
Property damage only	61	66.5	
Total	123	123.0	

[a]Based on 2.9 percent fatal, 43.0 percent injury, and 54.1 percent property damage only.
[b]See Figure 2.

Note that the number of fatal accidents is abnormally high for a total of 123 accidents (only 4 are expected). Therefore, it is necessary to comput the specific accident cost for this 2-lane road. Specific average cost of accidents on existing road is as follows:

Fatal	14 x \$95,000 =	\$1,330,000
Injury	48 x 3,000 =	144,000
Property damage only	61 x 900 =	61,000
Total	123	\$1,535,000
Average cost	\$1,535,000/123 =	\$12,480

The accident costs and savings are as follows:

Item	Number of Accidents	Cost of Accidents
2-lane road	987 x 1.93 = 1,905	1,905 x \$12,480 = \$23,770,000
4-lane freeway	958 x 0.85[a] = 815	815 x \$ 5,300[b] = 4,320,000
Savings	1,090	\$19,450,000
Safety index	(\$19,450,000/8,600,000) x 100 = 230 percent	

[a]0.8 average accident rate at average ADT of 20,200 (Fig. 1).
[b]Average cost of rural 4-lane freeway accident with normal distribution of severities (Table 2).

Spot Improvement Projects

Similar analyses are made for all spot improvement projects under the traffic safety program. Most projects are at individual locations such as an intersection or a curve. However, other projects, such as guardrail and delineation devices, can extend over a considerable length of highway. California is presently constructing 710 traffic safety spot improvement projects annually at a cost of about \$30 million.

Traffic volume increases, significance of past accident severity distributions, and the basic logic of the analyis are the same as outlined previously for major construction projects. The service life of geometric items is also taken as 20 years. The service lives of hardware items—signals, guardrail, and signing—are based on experience in California and vary from 2 to 15 years, depending on the item involved.

The prediction of accidents on the improved facility is handled somewhat differently in the spot improvement program. Analyses of approximately 500 "before and after" accident studies (2, 12, 13, 14, 15) have measured the percentage accident reductions that can be expected with various types of projects. These studies have also indicated that accidents cannot be reduced below a certain level or base rate. That is, even the best designed and operated intersection, for example, will have accidents. This analysis estimates that accidents can be reduced up to a given percentage, but that the resultant accident rate should not be less than the base rate. The average accident reduction factors are not used in all cases. The study of accident histories at individual locations sometimes indicate that higher, or lower, reduction factors are more

appropriate. Table 6 gives these criteria. Both the reduction factors and the base rates are subject to refinements as additional studies are completed. Note that accident rates at spot locations are reported in terms of accidents per million vehicles (MV) rather than million vehicle-miles (MVM).

The analysis technique also provides for 2 alternative methods of predicting accidents on improved facilities. The first provides for the engineering analysis of individual accidents and a determination of which accidents are susceptible to correction by the specific improvement proposed. This percentage reduction factor can be used as long as the reduced accident rate remains at or above the base rate. The reason for this limitation is that analysts sometimes neglect to consider trade-offs. For example, signal installations usually reduce right-angle accidents but often increase rear-end accidents. The other alternative analysis can be used in the case of guardrail projects, for example, where studies have shown that a reduction in the number of accidents may not be possible, but that a reduction in average accident severity (percentage of accidents that are fatal and injury) can be expected.

A typical spot improvement analysis is given for the following project in which it is proposed to improve a 2-lane conventional highway in a rural area by constructing left-turn lanes. The cost is $22,000 for construction; no additional right-of-way is required. The project life is 20 years. The 1969 ADT is 5,000 on the state highway and 1,600 on the county road; the 1989 ADT is expected to be 8,000 on the state highway. Travel generated is 62.6 million vehicles based on the sum of the ADT on the state highway and county road and on the assumption that the ADT on the county road will increase in the same proportion as that on the state highway. The existing accident rate is 0.98 accidents per million vehicles. The accident experience on the existing highway for the past 4 years is as follows:

Accident Severity	Observed	Expected[a]	Significant
Fatal	0	0.3	No
Injury	8	3.8	Yes
Fatal and injury	8	4.1	Yes
Property damage only	1	4.9	
Total	9	9.0	

[a]Based on 2.9 percent fatal, 43.0 percent injury, and 54.1 percent property damage only (Table 3).

The fatal category is not significantly high, but the injury category is. Therefore, the average cost of the past accidents (and the assumed cost of accidents in future without any improvements) is calculated as follows:

Fatal and injury	8 x $8,800[a] =	$70,400
Property damage only	1 x 1,000 =	1,000
Total	9	$71,400
Average cost	$71,400/9 =	$ 7,930

[a]Average cost of fatal plus injury accident (Table 2).

Table 6 gives a 50 percent accident reduction and a base rate of 0.60 A/MV with painted channelization at a rural, unsignalized intersection. A 50 percent reduction would give a final rate of 0.49 A/MV, which is lower than the base rate. Therefore, the base rate is used to predict accidents on the improved facility. Also, the average unit accident cost is used because the improvement should make the severity distribution normal.

TABLE 6

ACCIDENT REDUCTION FACTORS FOR HIGHWAY SAFETY PROJECTS

Type of Improvement	Average Accident Reduction (percentage of all accidents)	Accident Base Rate[a]
New signals	15	1.00 A/MV in urban areas, 1.25 A/MV in rural areas
Modified signals	10	
New signals with channelization	20	
Modified signals with channelization	35	
Left-turn channelization		
At signalized intersections	15	0.80 A/MV
At nonsignalized intersections		
With curbs and/or raised bars	65	0.40 A/MV
Urban area	70	0.40 A/MV
Rural area	60	0.50 A/MV
Painted channelization	30	0.80 A/MV
Urban area	15	1.00 A/MV
Rural area	50	0.60 A/MV
Flashing beacons		
Intersection flashers		
4-leg, red-yellow	50	1.10 A/MV
3-leg, red-yellow	50	0.70 A/MV
4-way, red	75	0.80 A/MV
Railroad crossing	80	0.20 A/MV
Advance warning flashers		
Curve and intersection	30	1.00 A/MV
New safety lighting		
At intersections	75[b]	0.80 A/MV[c]
At railroad crossings	60[b]	NA (assume 1.00 A/MV)[c]
At bridge approach	50[b]	NA (assume 1.00 A/MV)[c]
At underpasses	10[b]	0.70 A/MVM[c]
Delineation		
Median double yellow	5	0.45 A/MVM
Right-edge lines	2[d]	1.85 A/MVM
Reflectorized raised pavement markers	5	NA (assume 2.00 A/MVM)
No passing stripes	65[e]	2.60 A/MVM
Reflectorized guide markers		
At horizontal curves	30	1.10 A/MV
At bridge approaches	40	0.10 A/MV
Protective guardrail		
At bridge rail ends	50	0.30 A/MV
At embankments	50	1.20 A/MV
Pavement grooving		
Lengths less than 0.50 miles	75[f]	Dry accident rate
Lengths greater than 0.50 miles	75[f]	Dry accident rate
Signing		
Curve warning arrows	20	2.50 A/MV
Advance curve warning with advisory speed	20	1.80 A/MV
4-way stop	70	0.50 A/MV
Advisory speed sign	36	2.28 A/MV
Special curve warning arrow with stated speed	75	1.30 A/MV
Reconstruction and miscellaneous[g]	20[h]	
Less than 0.50 miles in length		
Rural conventional roads		1.00 A/MV
Urban conventional roads		1.33 A/MV
Rural and urban freeways		0.50 A/MV
Greater than 0.50 miles in length		—[i]

[a] A/MV = accidents per million vehicles; A/MVM = accidents per million vehicle-miles.
[b] Night accidents only.
[c] Nighttime rates based on one-third ADT.
[d] Or 25 percent of ran-off-road accidents.
[e] Or 85 percent of passing accidents.
[f] Wet pavement accidents only.
[g] Widen, superelevation, correct, construct shoulder, increase curve radii, and increase sight distance.
[h] Or reduction based on study of individual accident reports.
[i] Applicable statewide accident rates in Table 1, or 0.8 of rates if constructed to high standards.

The number and costs of accidents with or without the improvement is computed as follows:

Rate x million vehicles = number of accidents x unit cost = total cost

The savings with the improvement are, therefore, as follows:

Without improvement	0.98 x 62.6 = 61 x \$7,930 = \$484,000
With improvement	0.60 x 62.6 = 38 x \$4,600 = \$175,000
Savings	23 \$309,000
Safety index	(\$309,000/22,000) x 100 = 1,400 percent

CONCLUSION

Although the safety index concept is relatively new and modifications and refinements are desirable and are being made, this tool has proved to be helpful in evaluating safety benefits of major construction and spot safety improvement projects. The index is making possible more informed and better decisions in scheduling these projects.

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Appendix

STATUTORY CONSTRAINTS ON THE DISTRIBUTION OF STATE HIGHWAY FUNDS

Certain types of programs are designated as segregated expenditures and must be expended as outlined here. These programs include major construction, right-of-way acquisition, engineering, right-of-way acquisition overhead, traffic safety projects, signing and striping, minor improvements, thin blankets, office and maintenance building construction, and certain state subventions to local agencies (matching funds for federal-aid secondary construction on county roads, funds to cities and counties for urban extensions, and assistance to local agencies for constructing railroad grade separations). For the 1969-70 fiscal year it is estimated that $738 million out of a total budget of $855 million will be subject to the segregated expenditure constraints.

North-South Split

The total segregated expenditures of each fiscal year must be allocated 55 percent to the southern 13 counties and 45 percent to the northern 45 counties. Included in these total expenditures are all the programs previously mentioned regardless of whether the underlying revenues are from the state or the federal government.

District Minimums

The southern half of the state is further subdivided into 6 regions and the northern half into 7. Seventy percent of the total segregated expenditures in discrete 4-year periods must be expended according to statutory prescribed percentages for each of the regions after the 45-55 split has been made. The remaining 30 percent can be expended at the discretion of the California Highway Commission in any southern region for the south funds and in any northern region for the north funds.

The percentages that must be spent in each of the geographic regions are recomputed each 4 years so that they correspond to the relative 10-year needs of each region within its north or south portion of the state.

County Minimums

In addition, a minimum of $4 million in each of the 4-year periods must be spent in each county with the exception of 2 counties where only $3 million need be expended.

Discussion

J. P. MILLS, JR., Virginia Department of Highways—I have reviewed the paper by Tamburri and Smith with great interest. I am in full agreement with the objective of developing a more sophisticated approach to the scheduling of highway projects than is generally followed in most states, cities, and counties. The approach to the problem in California appears to have much potential and a great deal of merit. However, to use this approach on a statewide basis, accident records and reporting must be available and uniform throughout the state.

In Virginia, as in many other states, there appear to be variations in reporting accidents in urban areas. Based on population, some cities are submitting many more reports than others. If the reporting system is not uniform, then, naturally, biased results will be obtained.

In using the safety index system, it seems that urban roads should be arrayed against urban roads and rural against rural. It would be interesting to work up a few examples and see if this is true. Although I am sure that this system can be used to good advantage on stopgap projects, I am not sold on it.

Stopgap projects, as we know them in Virginia, generally range in cost from $1,000 to $100,000. They are initiated for 1 of 2 reasons—safety or congestion. One or both are usually outstanding and easily justified.

I doubt if accurate results could be obtained by using this system on roads in the western mountainous sections of our state. I refer to these roads where the alignment is so bad that accidents do not occur. However, straighten the roads and sometimes the accidents and severity both increase.

In conclusion, I am in full agreement that this system has great potential on our heavily traveled roads, as well as on stopgap projects of a similar nature. However, the accident data must be full and uniform on a statewide basis if allocations are to be made on this same basis.

VICTOR J. PERINI, JR., Highway Users Federation for Safety and Mobility—Perhaps I should preface my brief remarks by admitting that I am a lawyer and not an engineer. Consequently, I must plead the Fifth Amendment to any questions involving the curve of skewness, whatever that may be.

I do wish to commend Tamburri and Smith for their excellent paper. As a tool for making more effective priority decisions, the safety index system will become increasingly useful as needed data become more comprehensive and accurate. I will not attempt to comment on the mathematics involved in the index, but I assume that everything is correctly tallied and totaled.

It is evident that considerable thought was given by the authors to the question of accident severity, and to the introduction of severity into the computation. I would hazard a guess that, if somehow we could accurately assess both immediate and long-range economic impacts on the surviving family when its breadwinner dies on the highway, including such often-overlooked costs to the public resulting from possible governmental assistance to the survivors (through Social Security, Aid to Dependent Children, or other such programs) and not forgeting possible costs of litigation that might arise in settling claims, the $95,000 figure used by the authors as the accident cost of a rural fatality might be on the conservative side. I am not quarreling with the figure of $95,000, but this does raise another point that might merit a brief observation.

My experience as a trial lawyer in the field of automobile negligence litigation, which concerns itself with civil restitution of money damages resulting from automobile crashes where fault is found, has made me very much aware of the fact that the severity of impact of the vehicles involved in a crash may have little to do with the extent of injury or cause of death to drivers and passengers. Let me clarify this quickly: Every collision involves a series of chance circumstances that can have a very great influence on the final outcome of the incident. A relatively minor collision becomes fatal because someone is thrown from the car, through the windshield, or against some portion of the vehicle's interior that turns a bump into a penetrating wound. A concussion injury to a young man may prove fatal to an elderly person. Use or nonuse of seat belts can make the difference between a sore stomach or a quiet funeral. In each of these situations, the severity and location of impact on the vehicle can be comparable; only the results are starkly different.

This suggests that many accident analyses might point out a particular location for priority attention because of chance circumstances that turn an injury or property-damage-only accident into a fatality. And conversely, a possibly more hazardous location may be given a lower priority because crashes at this location, even with comparable fact situations and severity of impact of the vehicles results in minor or no injury. I know that the authors were aware of this problem, and have reduced the possibility of chance affecting their decisions by using a statistical technique that my engineering friends assure me is reasonable. Again I will take the Fifth Amendment to any questions directed to me concerning the technique.

Perhaps what I am struggling to say is that the severity of impact on the vehicle is probably easier to measure at the scene than the effect of the impact on the people involved. And yet the police officer frequently attempts to indicate the severity of injury to the victims and limits information about severity of damage to the vehicle by just reporting damaged areas and placing a dollar "quesstimate" of vehicle repair costs. In effect, the emphasis is placed on the aspect of the crash that is of lesser value to the engineer, although of possibly great value to people concerned with the medical aspects of vehicle collisions. What is more important to the engineer is the vehicle damage, which is the reflection of the severity of the impact. And because some of my best friends are engineers, I would not want this situation to continue. Therefore, I shall plunge forward bravely and mention something that makes a certain amount of sense to me.

I am advised that one method that could aid in measuring crash severity is use of the traffic accident data project pictorial damage scale. Essentially the pictorial damage scale is a series of photographs of crash-damaged vehicles with varying degrees of similar type of damage illustrated on each photograph. A police officer at the scene can measure severity of damage by comparing the crashed vehicles with the photograph on the scale that most closely portrays the actual damage incurred. A crash severity value is thereby determined. The use of such a scale will permit the officer to report a more meaningful estimate of severity of impact, which, of course, is important information to the engineer in determining hazard potential of a location. If average accident costs were computed for each severity class appearing on the pictorial scale, the safety index approach for using dollar amounts would still be used. And, finally, I am informed that the use of a pictorial damage scale in every state would be a big step in achieving nationally uniform data relative to collision severity.

I would certainly hope that my remarks are in no way construed as criticism of the safety index presented by these distinguished authors. Rather I would want my remarks to be considered as a plea for more usable data that would help Tamburri and Smith develop even better techniques.

THOMAS N. TAMBURRI and RICHARD N. SMITH, Closure—The authors are grateful for the kind comments of Mills and Perini.

Mills is concerned that the nonuniform reporting level of accidents would have an effect on the validity of the safety index in establishing priorities between projects in rural and urban areas. Because of the nonuniformity of reporting, he feels that urban projects can be compared only with other urban projects, and rural projects only with other rural projects. A previously reported study (10) determined the percentage and cost of accidents by various categories, such as fatal, injury, property damage only, rural, urban, conventional, and freeway. Accident costs used in safety index determinations are adjusted upward so that total costs determined by this method include the cost of unreported accidents. Because the safety index calculation includes both reported and unreported costs, all types of projects can be compared to one another.

Mills further feels that the safety index cannot be used on stopgap projects ($1,000 to $100,000), except those of a similar nature. Although the safety index can be used for justification (on the basis of safety only), its primary objective is to rate on a priority basis large numbers of worthwhile projects. When funds are limited (and they always are), the safety index is a tool for determining which projects give the greatest safety benefits per dollar expended so that the projects with the highest safety returns per dollar can be programmed earliest. This method results in greatest total safety benefits and the earliest safety benefits for the limited available resources.

It is true that some roads are so poor geometrically that they have a good safety record. In these cases, the safety index calculations do indicate that little or no safety benefit can be expected. However, other considerations, such as lack of capacity and maintenance costs, may indicate that the project is worthwhile nevertheless.

Perini suggests the use of the traffic accident data project pictorial damage scale to refine the safety index analysis. There is a considerable area of chance occurrence in traffic accidents, and this is precisely the reason that we used a statistical test, as Perini has observed. The difference between a fatal and an injury accident, or an injury and a property-damage-only accident, can be a very fine line indeed. It is also true that certain sections of highway do have considerably higher proportions of the more severe accidents. This becomes more apparent and more certain as the accident sample size becomes larger. Despite chance, the proportion of fatal accidents and injury accidents for a given road type in a given area is oftentimes remarkably stable.

The authors agree that the pictorial scale method has a potential for refining the method and should be investigated.

Cross-Median Crashes

PAUL H. WRIGHT, JOHN S. HASSELL, JR., and BERT ARRILLAGA, School of Civil Engineering, Georgia Institute of Technology

Even though cross-median crashes are rare events, evidence has shown that this type of crash tends to be severe in terms of vehicular damages and extent of personal injuries. Because these crashes occur so infrequently, detailed study exclusively utilizing empirical techniques would be time-consuming and expensive. For this reason, computer simulation was selected for an investigation of this problem. The simulation model described a 4-lane expressway in which cars were randomly released to cross the median at a right angle and at a constant speed. No provision was made for the driver to brake or regain control of the car. Opposing vehicles were generated by the negative exponential distribution. The effects of the following variables on probability of crash and average impact speed were studied: lane volume, speed of opposing vehicles, speed of crossing vehicles, median width, perception-reaction time, and skid resistance. It was found that, for those vehicles crossing the median, the probability of a crash was significantly increased by (a) increase in lane volume, (b) decrease in median width, (c) decrease in vehicle speeds, and (d) increase in reaction time. Skid resistance was of least importance in reducing crash probabilities. It was further found that average impact speed was significantly increased by (a) increase in vehicle speeds, (b) increase in reaction time, and (c) decrease in median width. Impact speed was little influenced by skid resistance and lane volume.

•THE ENCROACHMENT of vehicles on medians of divided 4-lane highways is relatively rare. Hutchinson and Kennedy (1) found frequencies that ranged from 1.0 to 14.1 encroachments per mile per year. The latter figure corresponds to the period of observation and test section having the highest traffic volume (31,253 vehicles per day). It was further found that the rate for 4-lane highways ranged from 47 to 561 encroachments per 100 million vehicle-miles (1).

In a study of accidents that occurred on Atlanta's 47.6 miles of expressways in 1968, the authors found that median encroachment crashes were also rare events. A study of 1,100 police reports (a 50 percent sample) of 1968 expressway accidents revealed that only about 11.6 percent involved one or more vehicles that entered the median or struck a median barrier. This would indicate a median encroachment accident frequency of 5.4 accidents per mile per year, a figure consistent with the previously quoted range. Only 4.0 percent of the total expressway crashes involved vehicles that actually crossed the median into opposing traffic lanes.

In vehicular collision research (2) for the National Highway Safety Bureau over the past 2 years, the authors have had the opportunity to observe first-hand vehicular collisions in general and cross-median crashes in particular. These observations have led to the conviction that despite their relative rarity, the cross-median type of crash is a serious roadway problem. Ancillary study of these crashes has strengthened this belief.

The seriousness of this problem is shown by the fact that there were 10 fatal cross-median crashes on Atlanta's expressway system in 1968 resulting in 13 deaths, constituting 54 percent of the total expressway deaths. It was found that crashes involving

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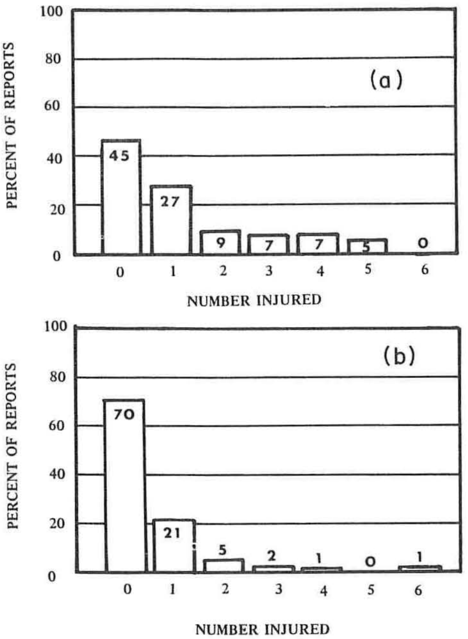

Figure 1. Number of persons injured in median encroaching crashes involving (a) vehicles that crossed the median, and (b) vehicles that did not cross the median.

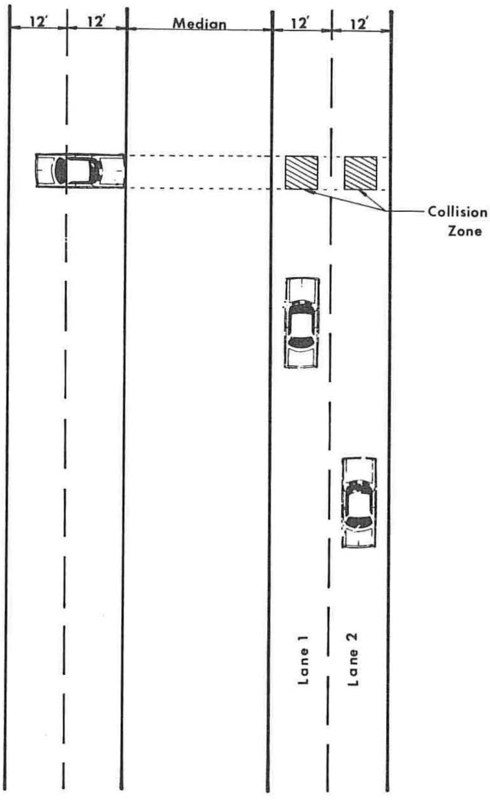

Figure 2. Simulated roadway and vehicles.

a vehicle that crossed the median tended to be more severe in terms of injuries and vehicle damages than those involving a vehicle striking a a median barrier.

Frequency diagrams for the number of occupants injured in each crash are shown in Figure 1. These diagrams indicate that 54.5 percent of the cross-median crashes had one or more injuries. In comparison, only 29.8 percent of those crashes involving non-crossing vehicles had one or more injuries.

The study of police reports further indicated that the cross-median crashes involved an average of 2.40 vehicles per accident, whereas those striking a guardrail or other median barrier involved only 1.23 vehicles per accident.

Because of inadequate information on the police reports, it is not possible to make conclusive statements regarding the relative severity of cross-median crashes and crashes involving vehicles stopped by a median barrier. One question left unanswered, for example, is, Would the vehicle that was stopped by a median barrier have encroached into opposing traffic lanes had the barrier not been present? The evidence from the police reports does, however, lend credence to the authors' concern regarding the seriousness of cross-median encroachments.

SIMULATION STUDY

How severe are cross-median crashes? Are these crashes characterized by high impact speeds as observations would suggest? What is the probability of a crash occurring once a vehicle encroaches into opposing traffic lanes? Seeking an answer to these and similar questions, the authors undertook further study of this problem. Because of the relative rarity of these crashes and the inadequacy of police records, it

was decided to study this problem by computer simulation, using the Burroughs B-5500 computer and ALGOL language.

The Computer Model

Basically, the simulation model described a 4-lane, 2-way highway with an unprotected center median. Some of the features of the model were as follows:

1. The highway had lane widths of 12 ft and a variable median width.
2. A crossing car was released at a random instant at the far median edge and permitted to cross the median at a right angle and a constant speed. Each vehicle thus released encroached into the opposing traffic lanes, and no provision was made in the program to brake vehicle or to recover control of it.
3. Oncoming vehicles in each of the opposing lanes were generated by the negative exponential distribution and, for a given run, were assumed to be traveling at equal constant speeds.
4. A crash was defined as occurring when the crossing vehicle and one of the opposing vehicles attempted to occupy the same space, called the collision zone, at the same time. This space was a square with 6.5-ft sides that represented the width of the vehicles. The time the collision zone was occupied by a vehicle was computed from the vehicle speed and length, assumed to be 17.5 ft (Fig. 2).
5. For a given run, a constant perception-reaction time was used, and, after a delay equal to this value, the driver of the opposing vehicle was allowed to apply his brakes and attempt to skid to a stop. Neither vehicle was allowed to change directions of travel.
6. The computer program kept account of the number of crashes and the speed of impact and computed the probability of crash and the average speed of opposing vehicle at time of impact.
7. A run consisted of 500 independent trials. For a given run, vehicle speeds, median width, skid resistance, and reaction time were assumed to be constant. A total of 432 runs were made, consisting of all possible combinations of the following variables:

Notation	Source of Variation	Amount
B	Lane volume, vehicles per hour	400, 800, 1,200, 1,600
C	Speed of opposing vehicles, mph	50, 60, 70
A	Speed of crossing vehicles, mph	20, 30, 40
D	Median width, ft	10, 20, 30
F	Perception-reaction time, sec	0.50, 1.0
E	Skid resistance	0.50, 0.65

To facilitate the analysis of variance, 2 replications of each run were made. A general flow diagram for the computer program is shown in Figure 3.

RESULTS

In order to better understand the output of the computer simulation, an analysis of variance was performed whereby the effect of the previously mentioned variables on the probability of a crash and the average impact speed of the opposing vehicle was examined. The analysis of variance was designed as a completely factorial experiment considering the 6 variables as being fixed. It was felt that for the purpose of the analysis 2 observations per combination was sufficient, giving a total of 864 observations.

There was strong a priori belief that the main variables would significantly affect probability of crash and average impact speed. Indeed, this was the basis on which the main variables were chosen. The principal value of the analysis of variance was therefore to rank the main variables in order of significance and to provide a quantitative evaluation of the effect of interactions.

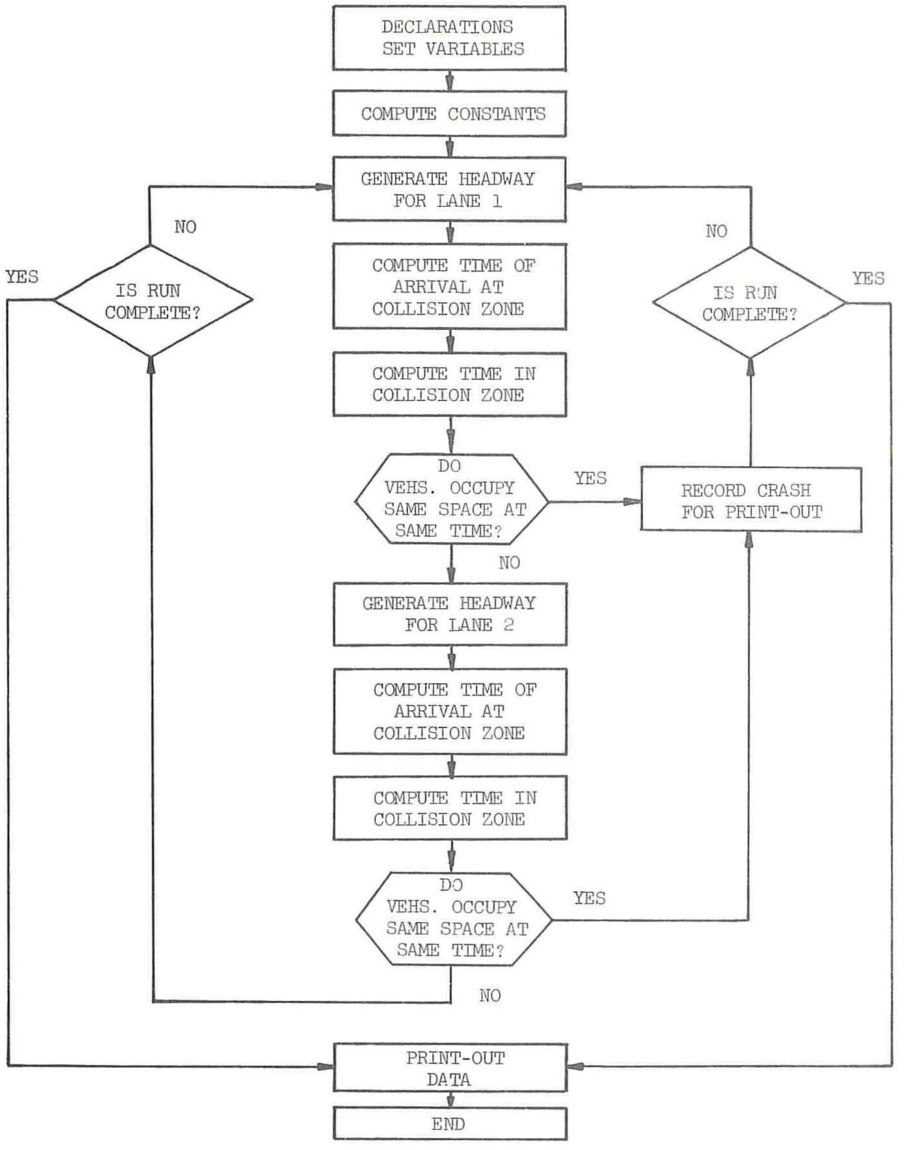

Figure 3. A general flow diagram for the computer program.

Probability of a Crash

All main variables and 12 interactions had a significant effect on the probability of a crash. These are given in decreasing order of significance in Table 1. The effect of the main variables, averaged over all the possible observations, is shown in Figure 4 and is discussed in the following terms of interesting interactions.

Lane Volume—As expected, probability of crash was most closely affected by the volume of traffic in opposing lanes. Crash probabilities ranged from about 0.35 for low lane volumes (400 vph) to as high as 0.75 at high lane volumes (1,600 vph). This relationship is shown in Figure 5.

Median Width—Increasing median width caused a significant but relatively small decrease in crash probability. This is shown in Figure 5 and also in Figure 6. It should be remembered that there was no opportunity to stop or to regain control of crossing

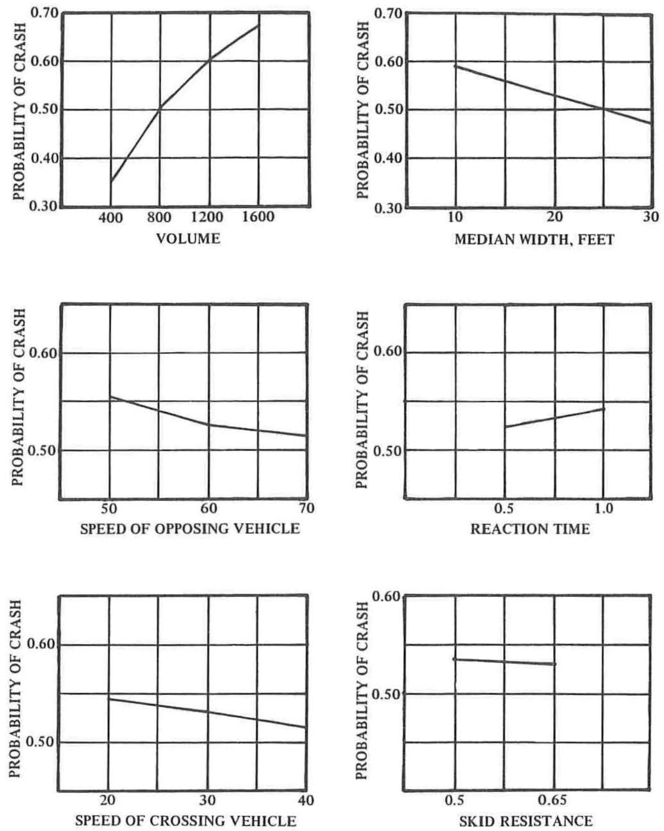

Figure 4. Average effect of main variables on probability of crash.

vehicles. The decrease in crash probabilities noted were principally due to the ability of certain of the opposing vehicles to stop.

Perception-Reaction Time—Perception-reaction time had only slight effect on the probability of crash. As expected, small perception-reaction times were accompanied by low crash probabilities. This is shown in Figures 6 and 7.

TABLE 1

VARIABLES AFFECTING PROBABILITY OF A CRASH

Source of Variation	Degree of Freedom	Mean Square	Source of Variation	Degree of Freedom	Mean Square
B	3	43,211.72	DF	2	58.23
D	2	9,699.60	AC	4	51.34
C	2	1,336.33	BF	3	29.99
F	1	625.26	AEF	2	29.39
A	2	521.73	DE	2	27.23
E	1	66.11	ACD	8	20.56
AD	4	104.27	CF	2	20.38
BD	6	91.84	BEF	3	20.15
AF	2	66.92	BC	6	13.23
			Experimental error	432	4.35

Notes:

1. One percent level of significance.
2. Four- and five-way interactions were not investigated.

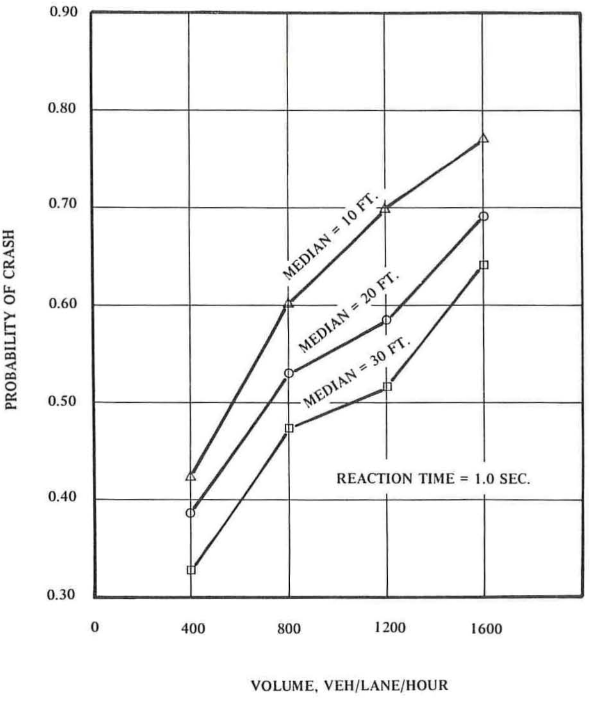

Figure 5. Effect of lane volume on probability of crash—skid resistance = 0.65, mph 1 = 20, mph 2 = 60.

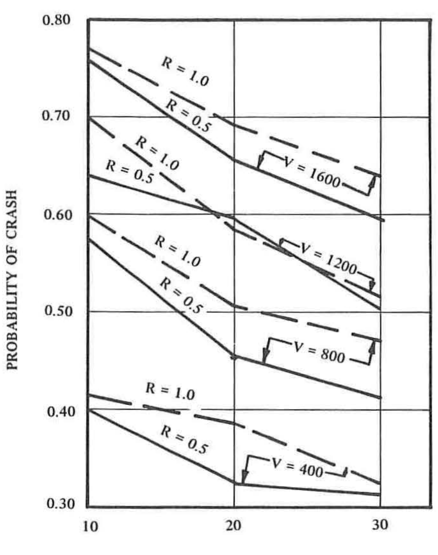

Figure 6. Effect of median width on probability of crash—skid resistance = 0.65, mph 1 = 20, mph 2 = 60.

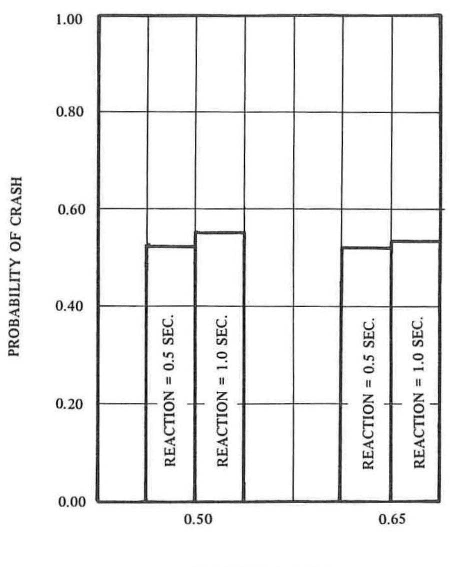

Figure 7. Effect of perception-reaction time and skid resistance on probability of crash.

TABLE 2

VARIABLES AFFECTING SPEED OF IMPACT

Source of Variation	Degree of Freedom	Mean Square	Source of Variation	Degree of Freedom	Mean Square
C	2	277,498,170.00	ADE	4	38,272.19
A	2	18,960,272.00	AEF	2	31,062.13
F	1	18,332,150.00	CF	2	23,220.13
D	2	9,470,100.90	DEF	2	23,104.50
E	1	928,463.37	AC	4	13,833.19
B	3	46,726.92	AB	6	10,095.33
AD	4	2,181,330.10	BF	3	7,208.00
AF	2	2,135,913.40	CD	4	5,416.19
AE	2	280,298.00	CEF	2	2,016.19
EF	1	273,600.37	CDE	4	1,071.28
DE	2	151,349.44	BDF	6	912.17
DF	2	145,698.60	Experimental		
ADF	4	42,323.91	error	432	319.05

Notes:
1. One percent level of significance.
2. Four- and five-way interactions were not investigated.

Skid Resistance—Figure 7 also shows that skid resistance had little effect on probability of crash. Skid resistance was varied over a narrow range of 0.50 to 0.65. This increase in skid resistance produced a decrease in crash probability generally less than 5 percentage points.

Vehicle Speeds—Crash probabilities decreased with increasing vehicle speeds, reflecting the smaller times the vehicles occupied the collision zone.

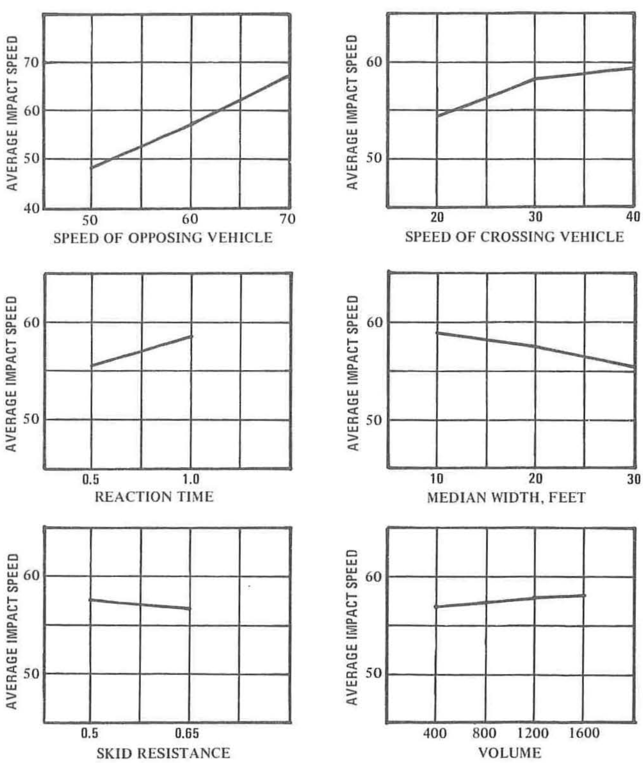

Figure 8. Average effect of main variables on average impact speed of opposing vehicle.

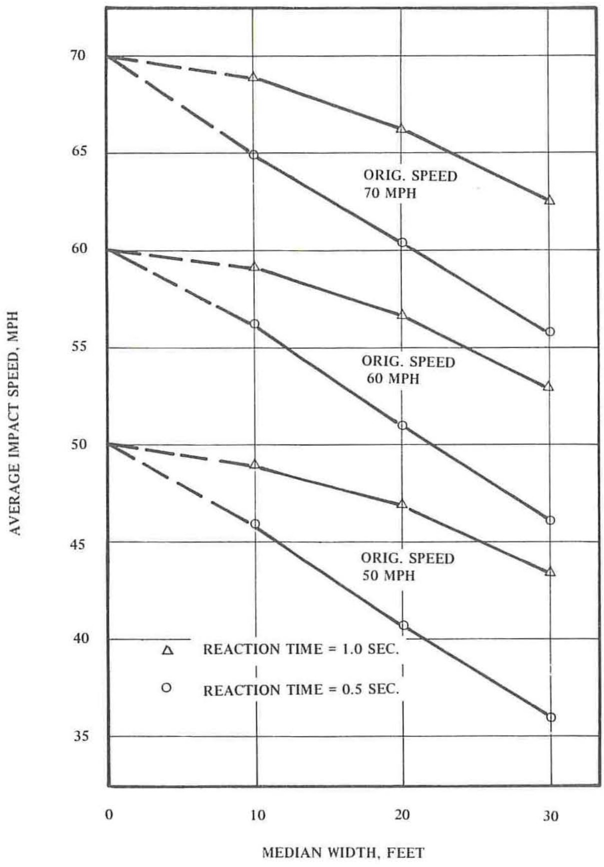

Figure 9. Effect of median width on average impact speed of opposing vehicle—volume = 400, skid resistance = 0.65, mph 1 = 20.

Average Impact Speed

It was similarly found that all the main variables and 18 interactions had a significant effect on the average impact speed of the opposing vehicle. Table 2 gives the variables and interactions in their order of significance, and, as before, the effect of the main variables is shown in Figure 8. These are discussed in detail in the following entries.

Median Width—Figure 9 shows the effect of median width on average impact speed. The decreasing impact speeds with wider median width reflect the ability of the average driver to slow his vehicle by braking. The principal interest in this figure, however, lies in the fact that such small decreases in impact speed were noted, even in the case of the 30-ft median width. The greatest decrease from the original speed shown by this figure is only about 14 mph. This dramatizes the fact that in cross-median crashes there is usually little time to react and slow a vehicle to tolerable impact speeds by braking. These results are consistent with the previously reported observation that cross-median crashes tend to have high impact speeds.

Perception-Reaction Time—Figure 9 also indicates the effect of perception-reaction time on average impact speed. With small perception-reaction times, a greater percentage of the available time is devoted to braking and lower average impact speeds result. This effect is also shown in Figure 10.

Skid Resistance—A change in skid resistance from 0.50 to 0.65 had little effect on average impact speed. Its effect, as expected, was to decrease impact speeds (Fig. 10).

Speed of Crossing Vehicle—Average impact speed of the oncoming vehicle increased with increase in speed of the crossing vehicle. This reflects the fact that at higher speeds for the crossing vehicle, there was less time for the driver of the oncoming vehicle to react and slow his vehicle by braking. This is shown in Figure 11, which also shows that, as the speed of the crossing vehicle increases, large median widths have less effect on decreasing average impact speeds. The latter finding suggests that median barriers are required on high-speed highways even where the median is wide if the violent and sometimes fatal cross-median crashes are to be reduced. This problem takes on greater significance when it is realized that as many as 20 percent of encroaching vehicles may cross a 40-ft median (1).

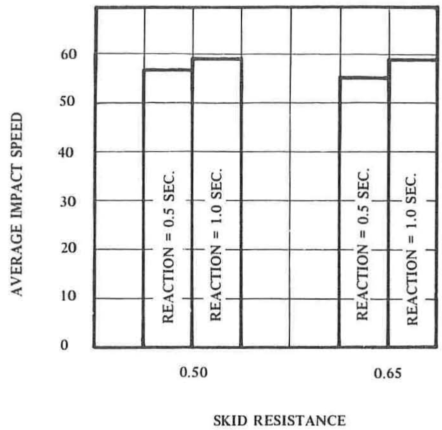

Figure 10. Effect of perception and reaction time on average impact speed of opposing vehicle.

EVALUATION OF THE COMPUTER MODEL

Because the model does not permit the crossing driver to stop or regain vehicle control, it clearly does not accurately simulate the behavior of all median-encroaching

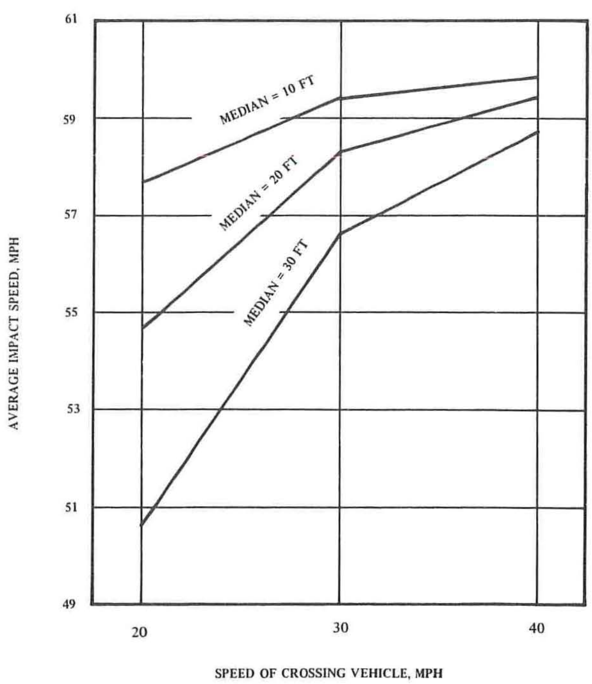

Figure 11. Effect of speed of crossing vehicle on average impact speed of opposing vehicle for various median widths.

vehicles. It simulates instead those vehicles that actually trespass into opposing traffic lanes. It should closely represent a vehicle in which both the brakes and steering have failed or in which the driver has "blacked out" or fallen asleep.

The model would also be expected to most accurately simulate situations where the median is narrow or the crossing speed is high or both of these. In these cases, a crossing driver would normally have little time to brake or regain vehicle control. For example, the driver of a vehicle crossing a 10-ft median at a speed of only 20 mph would have less than 0.5 sec to react before entering the collision zone. Similarly a vehicle crossing at 60 mph would require only about 0.4 sec to cross a 30 ft median and enter the collision zone.

It is recognized that the provision of a 90 deg angle of crossing, although simple to model, is a departure from reality. Hutchinson and Kennedy (1) found that encroachment angles were typically 25 deg or less, and the average encroachment angle was about 11 deg. To test the effect of angle of crossing, preliminary simulation studies have been made by using an angle of 11 deg and a crossing speed of 40 mph. Higher crash probabilities were found for the acute angle crossings, especially for the cases involving narrow medians. These initial studies indicate that the angle of crossing has little effect on average speed of impact for the opposing vehicle.

A more definitive analysis of crossings at acute angles will be the object of future research.

SUMMARY AND CONCLUSIONS

The computer simulation study was preceded by an empirical analysis of police reports of 1,100 expressway crashes that occurred in Atlanta, Georgia, in 1968. Results of this analysis supported the authors' belief that cross-median crashes, though rare in occurrence, tend to be severe in terms of vehicular damages and extent of personal injuries.

The simulation model used in this study described a vehicle that crossed an unprotected median at a right angle to the roadway centerline. No provisions were in the program for the crossing driver to brake or recover control of his vehicle. Significant findings from the study are given in the following:

1. For those vehicles crossing the median, probability of crash is most strongly influenced by the volume of traffic in opposing traffic lanes. Average crash probabilities varied from about 0.35 to about 0.68 over a range of lane volumes from 400 to 1,600 vph.
2. Probability of crash for crossing vehicles is also strongly influenced by width of median. However, increasing the median width from 10 to 30 ft reduced average probability of crash by only 11 percent. With a 30-ft median width, an average crossing vehicle still has a probability of crashing of almost 0.50.
3. Of the 6 factors studied (volume, median width, speed of opposing vehicle, speed of crossing vehicle, perception-reaction time, and skid resistance), skid resistance was of least significance in reducing probability of crash.
4. Average impact speeds for the opposing vehicle were high. Reductions from initial speed of travel were less than 5 mph on the average. This explains the observed tendency of cross-median crashes to be severe in terms of injuries and vehicular damages.
5. Average impact speeds of opposing vehicles decreased only slightly with increase in median width. An average decrease of only about 5 mph in impact speed was noted with an increase in median width from 10 to 30 ft. The decrease that was noted is attributed to the slightly longer braking time available in the case of wider median widths.

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The Interdisciplinary Development of Ambulance Design Criteria

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The wide variation in ambulance equipment and regulation of ambulance services, coupled with the development of federal safety standards for all types of vehicles operating on the highways, resulted in the National Academy of Engineering being asked to undertake a study of ambulance design criteria. This study was performed by an interdisciplinary committee consisting of physicans, ambulance operators, automotive engineers, and specialists in related fields. In addition to describing the organization and activities of the committee, this paper summarizes the major ambulance design criteria recommended by the committee and concludes with a listing of the elements essential for successful interdisciplinary efforts to solve a specific problem.

•THE INTRODUCTORY STATEMENT found at the beginning of the Highway Safety Program Manual (1) gives the reason for the establishment in 1968 of the Committee on Ambulance Design Criteria:

> Many of those injured in highway crashes die needlessly or are permanently disabled because they do not receive prompt and proper emergency care. Few areas of the United States now have adequate emergency services. In most areas there has been inadequate planning of emergency logistics, communications, and transportation facilities, and present services are inadequately managed. Ambulance operators, drivers, and attendants are commonly not required to be skilled in emergency care nor are they required in most parts of the country to carry adequate equipment in their vehicles. Hospitals and ambulances seldom have radio or other direct communications links either with each other or with police radio communications systems....It is imperative that highway and other Emergency Medical Services be improved throughout the nation.

Accurate information concerning the number of ambulances in the United States is not available, but it has been estimated that the ratio of ambulance vehicles to population may be about 1 per 5,000 persons (2).

In 1966 the Committee on Trauma and Committee on Shock of the Division of Medical Sciences, National Academy of Sciences—National Research Council, recommended (4) the "implementation of recent traffic safety legislation, to ensure completely adequate standards for ambulance design and construction, for ambulance equipment and supplies, and for the qualifications and supervision of ambulance personnel." This Committee found that no manufacturer produces an ambulance type of vehicle on an assembly line. Generally it was found (4) that "the bodies and fixed equipment of ambulances and rescue vehicles are produced by conversion of passenger-type vehicles or are fabricated to fit assembly line chassis, and are usually expensive in outward appearance, but impractical for resuscitative care."

In 1967 a task force on ambulance services reported that there was a wide variation in the equipment availability and regulation for ambulance services throughout the country. In many parts of the country, the Committee report (3) observed, "Anyone wishing to do so can purchase any type of vehicle he wishes, call it an ambulance, and charge for transporting the sick and injured, regardless of the appropriateness or quality of the service he provides."

Criteria were subsequently established for the training of ambulance personnel and others responsible for emergency care of the sick and injured at the scene and during

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transport (5). Implementation of these training procedures will enable ambulance attendants to be comparable to the combat medical corpsman in their ability to provide appropriate emergency care. But this upgrading of personnel has to be accompanied by the provision of more sophisticated equipment for use at the emergency scene as well as during transport of the injured to hospital facilities. Ambulances have to be designed so that they will ensure not only safe and efficient transportation and radio communication but also sufficient storage space and ready accessibility for fixed and mobile equipment, as well as room to adequately and actively treat any emergency that might arise while the patient is being transported. Thus it is that these improved treatment capabilities and increased requirements for facilities to handle emergency medical cases require new concepts in ambulance design.

At the present time many different types of vehicles, including station wagons, vans, hearses, and trucks, have been adapted for use as ambulances and rescue vehicles, but there are very limited and minimal national recommendations for the design of a truly emergency ambulance. The National Academy of Sciences—National Research Council Committee on Emergency Medical Services took cognizance of its earlier reports relating to deficiencies in ambulance services and the training requirements of ambulance personnel when it developed its most recent report "Medical Requirements for Ambulance Design and Equipment" (6). The most critical needs expressed in this report include increased space for administration of cardiopulmonary resuscitation in transit, a ceiling height sufficient for adequate gravity flow of intravenous fluids, installed oxygen and suction devices, 2-way radio communication, and storage room for equipment for optimal treatment and for rescue.

In 1968 the National Academy of Engineering was requested to undertake a study on ambulance design criteria for the National Highway Safety Bureau of the U. S. Department of Transportation.

INTERDISCIPLINARY ADVISORY COMMITTEE FORMATION AND ORGANIZATION

When one considers the design of an emergency ambulance, one immediately becomes aware of the fact that many and varied professional interests are directly concerned with this design. On the one hand are the medical interests who will utilize the vehicle, and on the other are the various automotive interests who will be called on to manufacture and maintain the vehicle. In between these 2 widely different professional interests are others including those who will be called on to operate the vehicle and those who are to provide adequate communications and ventilating facilities in the vehicle. Consideration must also be given to the operating environment for the vehicle.

Therefore, the Committee on Ambulance Design Criteria was established within the Highway Research Board of the Division of Engineering, National Research Council, as a part of that Division's cooperative effort with the Division of Medical Sciences to evolve suitable criteria for the vehicular design of ambulances. A complete list of committee members and the related staff personnel may be found in the Appendix.

Following the initial organization of the Committee in September 1968, subcommittees were organized in 5 areas of concern: (a) a comprehensive system description, (b) operational hardware and equipment, (c) vehicle standards, (d) communication equipment, and (e) environmental equipment. The first subcommittee developed a logical and comprehensive classification framework within which the various design criteria were to be developed by the remaining subcommittees. In the organization of the subcommittees, every effort was made to ensure that appropriate professional representation was present on each subcommittee and there could be a ready flow of communications between each of the subcommittees.

Three additional meetings of the Committee were held in November 1968, January 1969, and March 1969. An important element of the January 1969 meeting was a special ambulance exhibit held in Columbus, Ohio. This exhibit provided members of the Committee with an opportunity to obtain first-hand information about existing ambulances and their related equipment.

At this meeting, the Committee also had an open forum that enabled members to interact with more than 100 conferees from industries and technologies that had a concern for ambulance design. Various presentations were made by members of the Committee and staff to explain the Committee's objectives and progress to date. A question-and-answer period followed, and many valuable suggestions were received from members of the audience.

The final report of the Committee, "Ambulance Design Criteria", was transmitted to the National Highway Safety Bureau on June 30, 1969. This report is now being reviewed by appropriate personnel of the Bureau and other interested agencies.

PURPOSE AND SCOPE OF THE COMMITTEE'S ACTIVITIES

The objectives of the Committee on Ambulance Design Criteria and the purpose of its final report "are to determine and document performance and design criteria for an ambulance vehicle in sufficient detail that automotive designers can produce a vehicle suitable not only to present day practices, but also with adequate provision for future advances in equipment and administration of emergency care" (7).

The scope of the Committee's activities was described in 3 different parameters: the type of vehicle to which the criteria would apply, the vehicle elements or characteristics for which criteria were developed, and the scope of individual standards that were recommended for the vehicle elements and characteristics.

The term "ambulance" implies vehicle scope, but it is necessary to clearly define what is meant by an ambulance. The Committee decided that a vehicle should not be termed an ambulance unless it is designed, built, equipped, and staffed to cope with medical emergencies outside the hospital. The Committee adopted the following explicit definition (7):

> The ambulance is defined as a vehicle for emergency care which provides a driver compartment, and a patient compartment which can accommodate two emergency medical technicians and two litter patients so positioned that at least one patient can be given intensive life-support during transit; which carries equipment and supplies for optimal emergency two-way radio communication, for safeguarding personnel and patients under hazardous conditions, and for light rescue procedures; and which is designed and constructed to afford maximum safety and comfort, and to avoid aggravation of the patient's condition, exposure to complications, and threat to survival.

The military field ambulance was excluded from the Committee's considerations because of its unique and specific uses. Also excluded from consideration were vehicles that were utilized for elective transport of nonemergency patients, for medium and heavy rescue procedures, or for specialized intensive care, because these vehicles did not qualify in all respects to this definition. Therefore, the Committee concluded that a single type of vehicle can fulfill the requirements of an emergency ambulance.

Because automotive vehicles generally have hundreds of elements or components and each of these may have varied design or performance characteristics, the Committee decided to consider only those elements or characteristics that bear most directly on the safety and medical requirements of patients and ambulance personnel. In other words, those characteristics considered were those distinguishing the vehicle as an ambulance.

In the Committee report more than 100 individual elements and characteristics are identified to cover areas such as size and space requirements, mechanical performance, electrical systems, vehicle identification, communications equipment, climate control, supplies, and safety requirements.

Recognizing that a criterion for any design or performance characteristic can range from specific statements such as those found in production specifications to broad generalities expressed in undefined terms, the Committee tried to provide standards that were neither meaningless through their ambiguity nor so specific that the automotive designer would have no freedom for exercising further judgment and ingenuity. Generally, the more critical the individual design performance characteristic was, the more specifically it was defined or described by the Committee.

Some of the more significant criteria developed by the Committee can be used to highlight the principal implications that may be drawn from the complete set of recommendations. These criteria are as follows:

1. The patient compartment should be designed primarily for medical care in transit, including external cardiac compression, and should be unencumbered by equipment not essential to patient care. Inside, the ambulance should be large enough to transport 2 litter patients and 2 technicians with space around the patients to permit a technician to administer life-supporting treatment to at least 1 patient during transit.
2. Regardless of local circumstances that may influence the extent to which optional equipment may be employed, the manufacturer's product should be sufficiently standardized to provide the space not only for required installed and portable equipment and supplies but also for optional items now available and for adaptation to more advanced equipment that will become available.
3. Principal environmental requirements for medical care include sustained environmental control and ventilation that minimizes contamination from outside air.
4. Communications requirements include 2-way radio, walkie-talkie, intercom, and public address systems.
5. External identification (lights, colors, and markings) should be standardized on a national basis. The Committee recommends using blue and white rotating beacons and flashing blue roof lights for warning signals, and crosses of Omaha orange on the white roof, rear, sides, and front of the vehicle. The word "ambulance" should be written in large, black letters under the crosses and on the front in a mirror image for identification by drivers ahead of the ambulance.
6. Privacy and efficiency would be enhanced by the omission of windows in the patient compartment.
7. Acceleration capability should ensure that the ambulance is capable of rapid response, that it can avoid hazardous situations by maintaining its position in traffic, and that it can move faster than traffic when advisable because of the patient's condition. The vehicle should be capable of smooth performance at maximum speed limits on Interstate highways. The criteria of maximum acceleration and speed specified in the report are designed to ensure performance consistent with ambulance operation in traffic patterns on Interstate highways. These high performance capabilities should not be interpreted to condone unsafe operation at any time.
8. Depending on whether the ambulance is built on a passenger car chassis or on a truck chassis, general federal motor vehicle safety standards for ambulances should be those applicable to the chassis employed (7).
9. The major physical dimensions specified by the Committee are as shown in Figure 1. It should be noted that maximum or minimum values are generally indicated with the exact value being left to the designer's initiative.

NEEDED RESEARCH

During the course of their deliberations the Committee identified 4 important vehicle characteristics for which definitive standards cannot be recommended until further research has provided suitable objective data. These characteristics are the color and intensity of identification lights, the riding quality and stability performance level ranges, the noise and vibration tolerance limits, and the vehicle braking system requirements.

The Committee recommended a blue color for flashing warning lights and an alternating blue and white color for rotating roof-mounted beacons. Blue was recommended because the human eye detects blue more quickly than other colors thus facilitating the quick identification of the ambulance as a life-saving emergency vehicle. Moreover, blue would not be confused with traffic signal lights and other identification signs and lights that are predominantly red, green, or yellow in color. The exact shade or density of color and the minimum and maximum output intensity are yet to be determined by research under test conditions. The Committee also recognized the problem that in many areas police or other emergency vehicles now use blue lights. While recognizing the difficulty of modifying statutes, the Committee was of the opinion that the criteria for

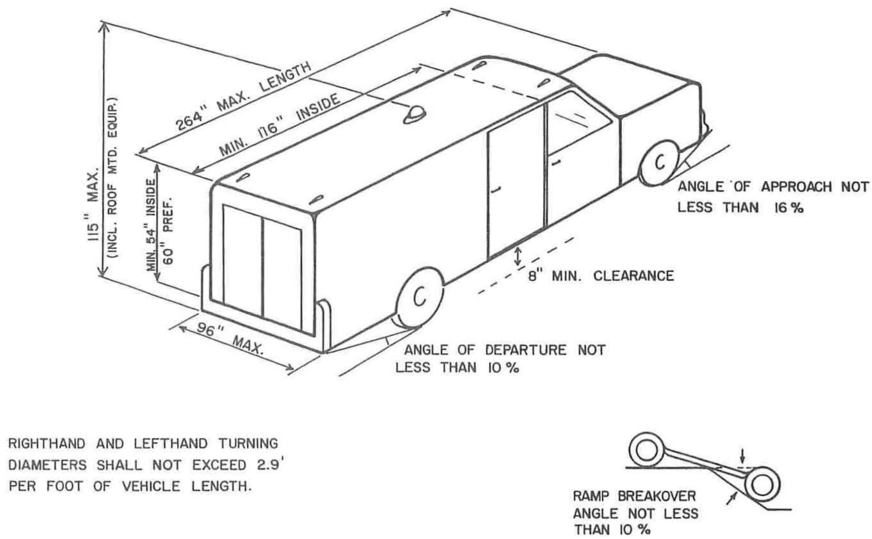

Figure 1. General physical characteristics for ambulance as developed by Committee on Ambulance Design Criteria (U.S.A.).

distinction of ambulances should be nationally uniform, and that restriction of blue lights to identification of ambulances is feasible and necessary.

When someone is sick or injured, he naturally desires a smooth ride with due consideration of road conditions. At the present time there are no medical guidelines on which to quantify levels of movement and vibrations that may be deleterious to seriously ill or injured patients. Similarly, at the present time there are no definite standards concerning noise and vibration levels and their relative influence on the patient.

Although there are existing federal motor vehicle safety standards that refer to the vehicle braking system, it was the unanimous view of the experienced ambulance operators who were members of the Committee that the present ambulance braking system is the most common factor in vehicle maintenance because of the excessive braking requirements of ambulance operation. Thus, the Committee recommended that research be conducted to develop heavy-duty braking systems that could satisfy the unique braking requirements of ambulances.

GENERAL OBSERVATIONS

The organization and subsequent deliberations of the Committee on Ambulance Design Criteria provided an excellent opportunity to observe the development of what turned out to be a most cooperative interdisciplinary effort.

The selection of the members of the Committee was made by the Highway Research Board after consultation with appropriate and knowledgeable agencies and persons. Efforts were made to obtain the most competent person in each particular subject area, and these persons were also evaluated as to their potential for participating as part of the interdisciplinary team.

Initially there was some hesitancy on the part of the Committee members to frankly discuss the problem of ambulance design. This hesitancy can be explained by the fact that very few of the Committee members knew one another unless they came from the same professional discipline. For example, most of the physicians had worked together on previous medical committees relating to emergency services, but generally they were not acquainted with the experts from other disciplines.

There was also an initial problem of basic communications because the exposure of the various members to the ambulance and emergency service problem varied and was

generally from one particular point of view. Therefore, it was necessary to establish a basis of common understanding of the problem of transporting persons in emergency vehicles and a mutual understanding of technical terms.

As the Committee activities progressed, very free and frank dialogues developed. This was facilitated by the close contact and discussions that the members had while they were participating in the subcommittee activities and general committee meetings. These discussions helped create a better understanding of the various problems in transporting seriously injured and ill persons as well as a better understanding of technical terms and equipment use.

The basic operating goals of the Committee were relatively simple. All of the major and most of the minor decisions were made only after there had been thorough discussions and then they were resolved on the basis of majority vote. In some cases there were discussions to reconsider previous conclusions, and changes were made if they were approved by a majority of the Committee.

In order to facilitate thorough consideration of all pertinent design and performance criteria, the members were encouraged to freely participate in the discussions with normal courtesy being extended so that no one unduly monopolized the discussion. Depending on the subject matter, various persons would tend to participate more in some of the discussions because of their technical competence in that particular area.

As might be expected, not all of the decisions were unanimous, but all of the work of the Committee was done in a harmonious and cooperative way. When opinions differed greatly, every effort was made to find an acceptable compromise solution.

One of the basic problems that faced the Committee was the fact that ambulances as such are a very small part of the total number of vehicles built and operated on U. S. highways. Consequently, the Committee was continually confronted with the problem of whether it should limit its recommendations to the existing availability and capabilities of current vehicle components. Generally, the Committee decided that this should not be a limitation if changes could be justified for medical reasons.

The Committee also recognized that each ambulance will operate under different conditions and that an ambulance in a large metropolitan area will rarely be expected to travel off the paved streets. However, disruption of paving, flooding, and deposition of debris in natural disasters or civil disorders can frequently immobilize current emergency vehicles in urban as well as rural areas. An ambulance in an undeveloped rural area may spend quite a bit of time on poorly maintained roads or in traveling across country. The Committee felt that all ambulances should be capable of travel in these varied circumstances and based its recommendations for pertinent vehicle performance characteristics accordingly.

The Committee realized that few ambulances now in service can be modified to adopt all of the criteria recommended by the Committee. The Committee, therefore, suggested that new ambulances now in use should be modified to the maximum extent that is physically feasible until they are replaced by more modern equipment that fully complies with the proposed design criteria.

Another very essential element of the Committee's successful operation was the very competent staffing and assistance provided by the Highway Research Board and the Division of Medical Sciences. Roland J. Sigafoo, Executive Secretary for the Committee, served in a full-time capacity and did an outstanding job in bringing together all of the various reports and recommendations as well as identifying voids and inconsistencies. His previous experience in bus manufacturing and as a member of a panel on an interdisciplinary committee that previously had developed design and performance criteria for nonrail urban mass transit vehicles gave him very valuable experience that also contributed to the Committee's productive efforts.

The smooth operation of the Committee was also greatly facilitated by the logical and comprehensive framework developed by the first subcommittee. This comprehensive system description was used to coordinate all of the activities and studies of the other subcommittees and provided a basis for coordination and integration of subcommittee recommendations.

The opportunity to view existing ambulances and meet with ambulance manufacturers and operators also helped the Committee in its work. As mentioned previously,

some members of the Committee were very experienced in ambulance operation and use whereas others had very limited knowledge of these problems.

CONCLUSIONS

Based on the experience of the Committee on Ambulance Design Criteria, the following elements are necessary for the successful application of interdisciplinary efforts to resolve a specific problem:

1. A clear definition of the problem and the purpose and scope of the interdisciplinary effort;
2. A realistic timetable for the programmed activity;
3. The identification and recruitment of those persons whose professional experience qualifies them to make a major contribution to the problem solution (the number of specialists should be kept to a practical minimum so that there will not be undesirable duplication of talent; however, all major professional and operational interests should be represented);
4. Competent and adequate staff personnel to undertake the group's production effort;
5. An adequate budget to allow for (a) attendance at all meetings of the group and its subunits by the professional members and staff, (b) availability of adequate supplies and materials, reproduction facilities, source documents, and all other necessary work materials, and (c) publication of interim and final reports;
6. Opportunities for the specialists and staff to observe problem situations and discuss these problems with persons intimately knowledgeable about them;
7. An unselfish, open-minded, patient, and cooperative attitude on the part of all who are actively engaged in the problem solution; and
8. A commitment on the part of those commissioning the interdisciplinary activity that the active participation and interest of all concerned is necessary for the solution of a very real problem and that the group's recommendations will be given thorough consideration.

ACKNOWLEDGMENTS

All of the necessary elements listed in the conclusions were present in the interdisciplinary effort reported here. It was a very gratifying professional experience to have the opportunity to participate in this project.

Grateful acknowledgment must be extended to all of the persons who were actively engaged in this activity (see Appendix). The Committee members and special advisors unhesitantly contributed freely of their time and resources and received no material compensation for their efforts except reimbursement of travel expenses. Special appreciation is extended to Paul E. Irick of the Highway Research Board, Sam F. Seeley of the Division of Medical Sciences, and Eugene E. Flamboe of the National Highway Safety Bureau for their patient and understanding monitoring of the project, and to Roland J. Sigafoo, whose service as Executive Secretary for the Committee was the mainspring of the whole operation.

The excellent cooperation of the various ambulance industry representatives, vehicle and equipment manufacturers, operators, and all others who assisted the Committee is deeply appreciated.

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Appendix

COMMITTEE ON AMBULANCE DESIGN CRITERIA

John E. Baerwald (chairman), Director, Highway Traffic Safety Center, University of Illinois, Urbana

Roland J. Sigafoo (executive secretary), Special Projects Engineer, Highway Research Board

System Descriptions Subcommittee

Robert F. McLean (chairman), Executive Engineer, Development Engineering Department, General Motors Corporation, Warren, Michigan

Marvin J. Herbert, Human Factors Psychology Department of Experimental Psychology, Army Medical Research Laboratory, Fort Knox, Kentucky

Peter Safar, Professor of Anesthesiology, Presbyterian-University Hospital, Pittsburgh, Pennsylvania

Operational Hardware and Equipment Subcommittee

David H. Slayback (chairman), Executive Director, The International Rescue and First Aid Association, Caldwell, New Jersey

Joseph D. Farrington, Lakeland Medical Associates, Chairman, NRC Subcommittee on Ambulance Services, Woodruff, Wisconsin

Rader O. Hale, Fleet and Leasing Department, Ford Motor Company, Dearborn, Michigan

Vehicle Standards and Vehicle Characteristic Limits Subcommittee

Harry R. Snyder (chairman), Chairman, Development and Research Committee, Ambulance Association of American, Van Nuys, California

Kenneth F. Kimball, Associate Professor of Surgery, University of Nebraska, College of Medicine, Kearney

Ralph A. Sarotte, Safety Engineer, Plymouth Product Planning Division, Chrysler Corporation, Detroit, Michigan

Communications Equipment Subcommittee

Richard C. Hopkins (chairman), Traffic Systems Division, Bureau of Public Roads, U. S. Department of Transportation, Washington, D. C.

Martin C. McMahon, Chief, Ambulance Service of Baltimore City Fire Department, Baltimore, Maryland

Environmental Equipment Subcommittee

Harold B. Parker, Air Conditioning and Heating Specialist, Consultant, Tampa, Florida

Arthur E. Brehm, Automotive Engineer, Design and Service Consultant, Manufacturers of Bus Component Equipment, Stow, Ohio

Special Advisors to the Committee

Irma M. West, Coordinator of the Injury Control Project, California State Health Department, Berkeley

Marie C. Dunn, Secretary, Oregon State Ambulance Association, Florence

Liaison Representative of U. S. Department of Transportation

Eugene E. Flamboe, Acting Division Chief, Accident Investigation, Systems Design, National Highway Safety Bureau, Washington, D. C.

Staff of Highway Research Board

Paul E. Irick, Assistant Director for Special Projects

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Clarence G. Johnsen, Professional Associate

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The NATIONAL ACADEMY OF ENGINEERING was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its Act of Incorporation, adopted Articles of Organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the Federal Government, upon request, on any subject of science or technology.

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Supported by private and public contributions, grants, and contracts, and voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

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The HIGHWAY RESEARCH BOARD, an agency of the Division of Engineering, was established November 11, 1920, as a cooperative organization of the highway technologists of America operating under the auspices of the National Research Council and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of transportation. The purpose of the Board is to advance knowledge concerning the nature and performance of transportation systems, through the stimulation of research and dissemination of information derived therefrom.

HIGHWAY RESEARCH BOARD
NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL
2101 Constitution Avenue Washington, D. C. 20418

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